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TECHNICAL REPORT RL-81-8

HAWK LAUNCHER SHOCK ABSORBER
(PART NUMBER 11567877)
FINAL TEST REPORT

John D. Alston
Ground Equipment and Missile Structures Directorate
US Army Missile Laboratory

July 1981

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the test methods and results of a series of tests to determine compliance of modified HAWK launcher shock absorbers with TDP requirements. The primary test was a dynamic impact of the shock absorber with a 1000-lb weight traveling at 28 in./sec. The force/time relationship during shock absorber actuation induced by this impact was recorded on an oscillograph and by a digital computer. Correlation of test results was excellent and performance of the shock absorbers was good. There were some areas of noncompliance to the performance requirements of the shock absorber TDP.

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- Mr. Frank Gasper and Mr. Bish Tarwater of the HAWK Project Office who provided requirements and guidance for this effort.

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I. INTRODUCTION

In late 1977 a major effort was initiated by the HAWK Project Management Office to investigate the problem of HAWK missiles being inadvertently dropped from launchers, and to take action to minimize these incidents in the future. Performance of the launcher shock absorber, PN 9091309, was identified as a major factor in preventing dropped missiles. The Raytheon Company conducted extensive analysis and testing of the shock absorber and recommended several minor but significant changes to the shock absorber. These changes were approved and, in July 1979, were incorporated into the Technical Data Package (TDP) by Engineering Change Proposal (ECP) MI-A4130. The new shock absorber was assigned part number 11567877. New shock absorbers will be fabricated per Drawing 11567877.

HAWK launchers are rebuilt at Letterkenny Army Depot (LEAD). Old shock absorbers, PN 9091309, can be modified to the new configuration. It is planned that LEAD will begin producing modified shock absorbers in the near future. In order to qualify their modification procedures, LEAD modified four shock absorbers to the new configuration and delivered them to Redstone Arsenal (RSA) for testing. This report documents the results of tests of these shock absorbers and of unmodified shock absorbers tested for comparison purposes.

II. TEST EQUIPMENT AND FACILITIES

The testing was conducted by personnel of DRSMI-RTS and DRSMI-RTR-LM, using their equipment and facilities located in Building 4500, Redstone Arsenal, Alabama. Personnel of DRSMI-RLD designed and managed local fabrication of the special adapters and fixtures used in the tests. DRSMI-RLD also provided test requirements, data reduction and analysis, and prepared the final report.

Four modified shock absorbers were delivered on 20 February 1980 by two technicians from LEAD, who participated in the initial testing and test result analysis. Two shock absorbers were received from the Raytheon Company, and a Raytheon engineer participated in a portion of the testing and test result analysis.

III. TEST REQUIREMENTS

There are three specific performance tests designated by the shock absorber TDP. The most significant test requirements are summarized below.

A. Check Valve Leakage Test

Drawing 11567874, Note 1, stipulates that the Guide, Spring Assembly, PN 11567874, be tested for leakage through the check valve at a pressure of 3000 psi. The leakage rate shall not exceed 50 ml of oil in 30 sec. Figure 1 of Drawing 11567874 defines a typical test fixture for this test.

B. Piston Return Time Test

Drawing 11567877, Note 8, states that the piston shall be held in a vertical position, piston down, with the piston fully compressed. When the piston

is released, it shall return to the fully extended position in not longer than 0.25 sec.

C. Drop Test

Drawing 11567877, Note 7, specifies the required energy absorption characteristics. Note 7A specifies that the item shall be tested with a test weight of 1000 ±25 lb at an impact velocity of 28 ±1 in./sec and defines the test setup. Note 7B stipulates that, after initial impact of the shock absorber piston shaft with the seat, the shock absorber body must travel 3.75 in. in a time interval of 0.30 to 0.42 sec. Note 7C stipulates that during the test stroke the maximum load on the shock absorber, as measured by a load cell, shall neither exceed 1650 lb nor fall below 750 lb.

IV. TEST SAMPLES

A total of nine shock absorbers were utilized in this series of tests. Three unmodified shock absorbers, PN 9091309, were borrowed from the Maintenance, Test, and Procedures Branch, DRSMI-NEX, at RSA. Four shock absorbers modified to the new configuration by LEAD were tested. Two shock absorbers modified to the new configuration by Raytheon, and previously used by them to establish the criteria defined in Drawing 11567877, were tested for comparison with units modified by LEAD.

The shock absorbers from LEAD and Raytheon conform to Drawing 11567877 except that they are a modification of Part 9091309, and, therefore, contain an extra fill port, have no fill port boss on the casting, and utilize a rivnut at the fill port. The four shock absorbers from LEAD utilize a 1/4-in. rivnut in lieu of the 3/8-in. rivnut specified, because they could not obtain the larger rivnuts in time to meet the test schedule. Each shock absorber tested was assigned a sample code number. Variations of the code number denote different configurations of the same test sample. The test sample code numbers are summarized in Table 1. The designations are defined in more detail later in this report.

V. TEST EQUIPMENT, PROCEDURES, AND RESULTS

A. Check Valve Leakage Test

1. Test Equipment. A special test fixture, PN GEM6172, was designed and fabricated for this test. This fixture is functionally equal to the fixture proposed in Figure 1 of Drawing 11567874, but is cheaper to fabricate and is easier and quicker to use.

2. Test Procedure. Prior to starting the testing, the test fixture was subjected to a proof test of 4500 psi using water as the pressurizing medium. The fixture successfully passed this test. Items to be tested were obtained by disassembling shock absorbers and removing the Guide, Spring Assembly, PN 11567874. The item to be tested was mounted in the test fixture, as shown in Figure 1, and then attached to a hydraulic console, as shown in Figure 2. Hydraulic oil was used for the pressurizing medium. The fixture was filled with

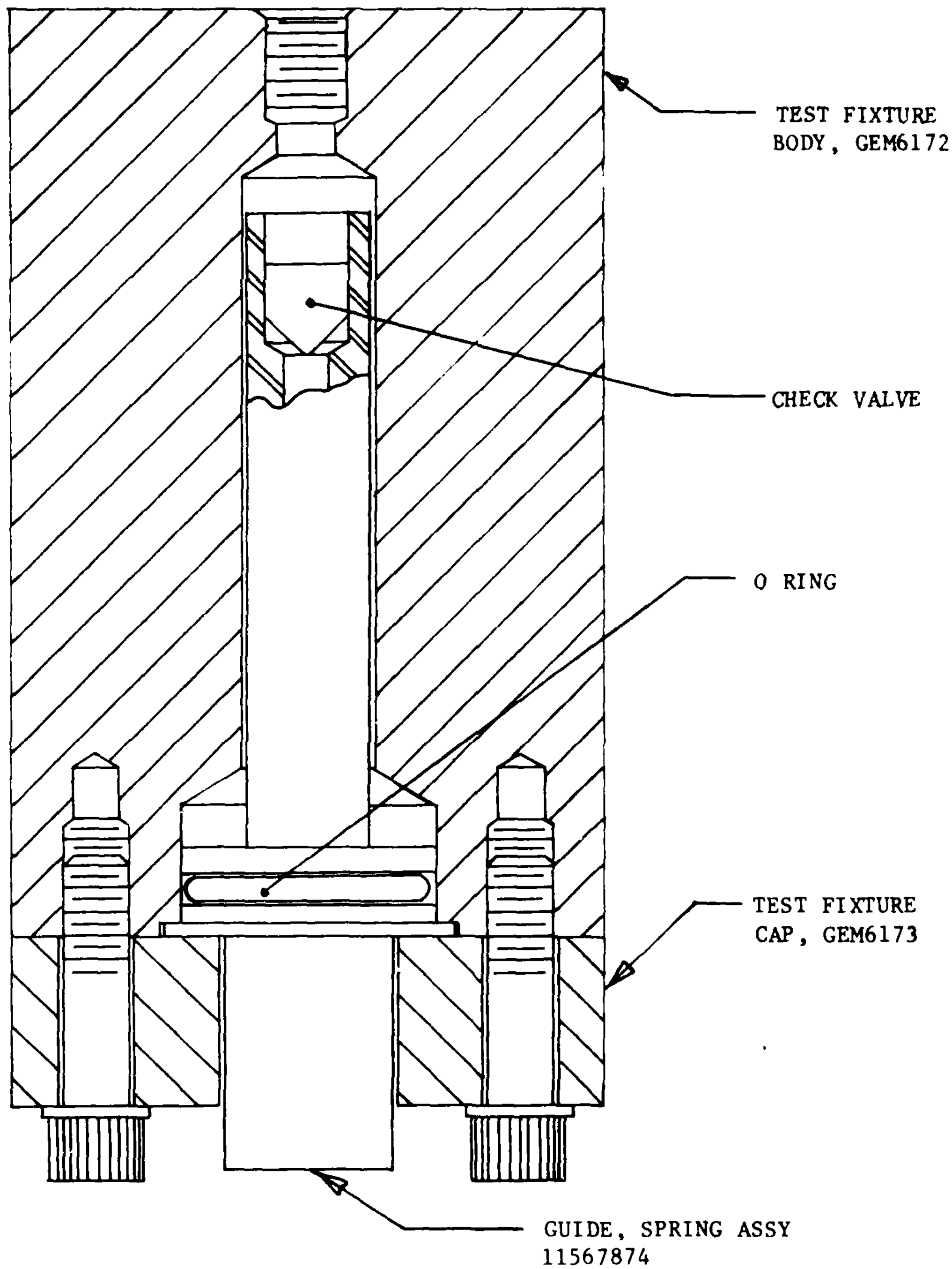


Figure 1. Check valve leak test fixture.

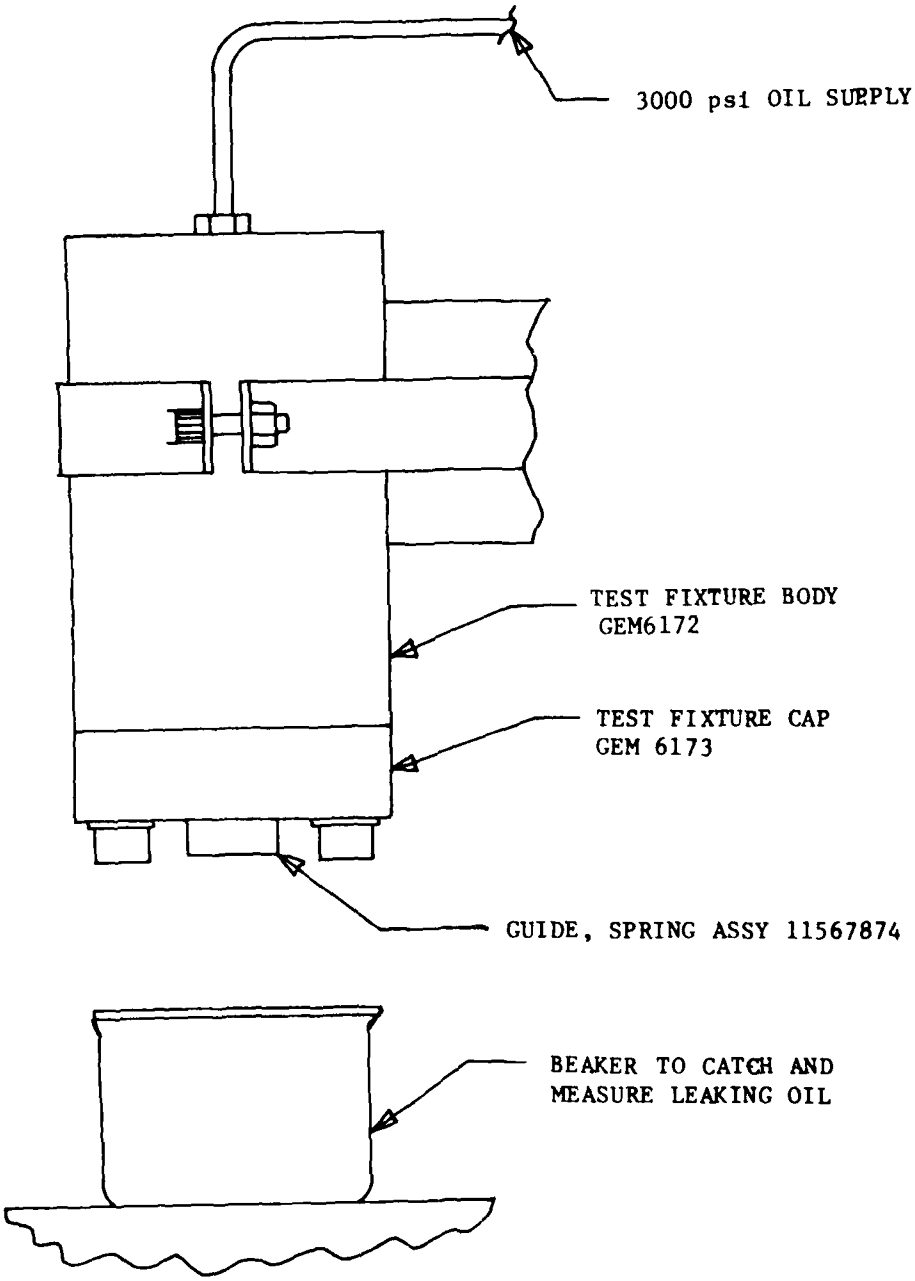


Figure 2. Check valve leak test setup.

Table 1. Shock Absorber Test Sample Chart

SAMPLE CODE	CONFIGURATION	SOURCE	COMMENTS
0	Unmodified	DRSMI-NEX	PABCO, SN 2787
1	Modified	LEAD	
1A	"	"	Sample 1 Reworked by LEAD after 11 February tests
2	"	"	
2A	"	"	Sample 2 Reworked by LEAD after 11 February tests
3	"	"	
3B	"	"	Sample 3 With a Non-standard Sleeve
4	"	"	
5	"	Raytheon	Raytheon Code L8, PABCO,NSN
6	"	"	Raytheon Code L4, Highway Products Inc., SN 85070
7	Unmodified	DRSMI-NEX	
8	"	"	PABCO, SN 1751

oil, and a pressure of 3000 psi was applied for one minute. The fixture was then disassembled, and a new Guide, Spring Assembly inserted for the next test. The tested unit was reassembled into the same shock asorber from which it had been removed.

3. Test Results. The Guide, Spring Assemblies from shock absorber samples 1A, 2A, 3, 4, and 5 (see Table 1) were tested for check valve leakage on 9 April 1980. None of the five units tested had any significant leakage in one minute at 3000 psi.

B. Piston Return Time Test

1. Test Equipment. A special test fixture, PN GEM6174, was designed and fabricated for this test. This fixture is shown schematically in Figure 3. The fixture holds the shock absorber in a vertical position, and a screw thread mechanism is used to retract the piston. The rotating arm holds the piston in the retracted position, and a linear potentiometer contacts the tip of the piston shaft.

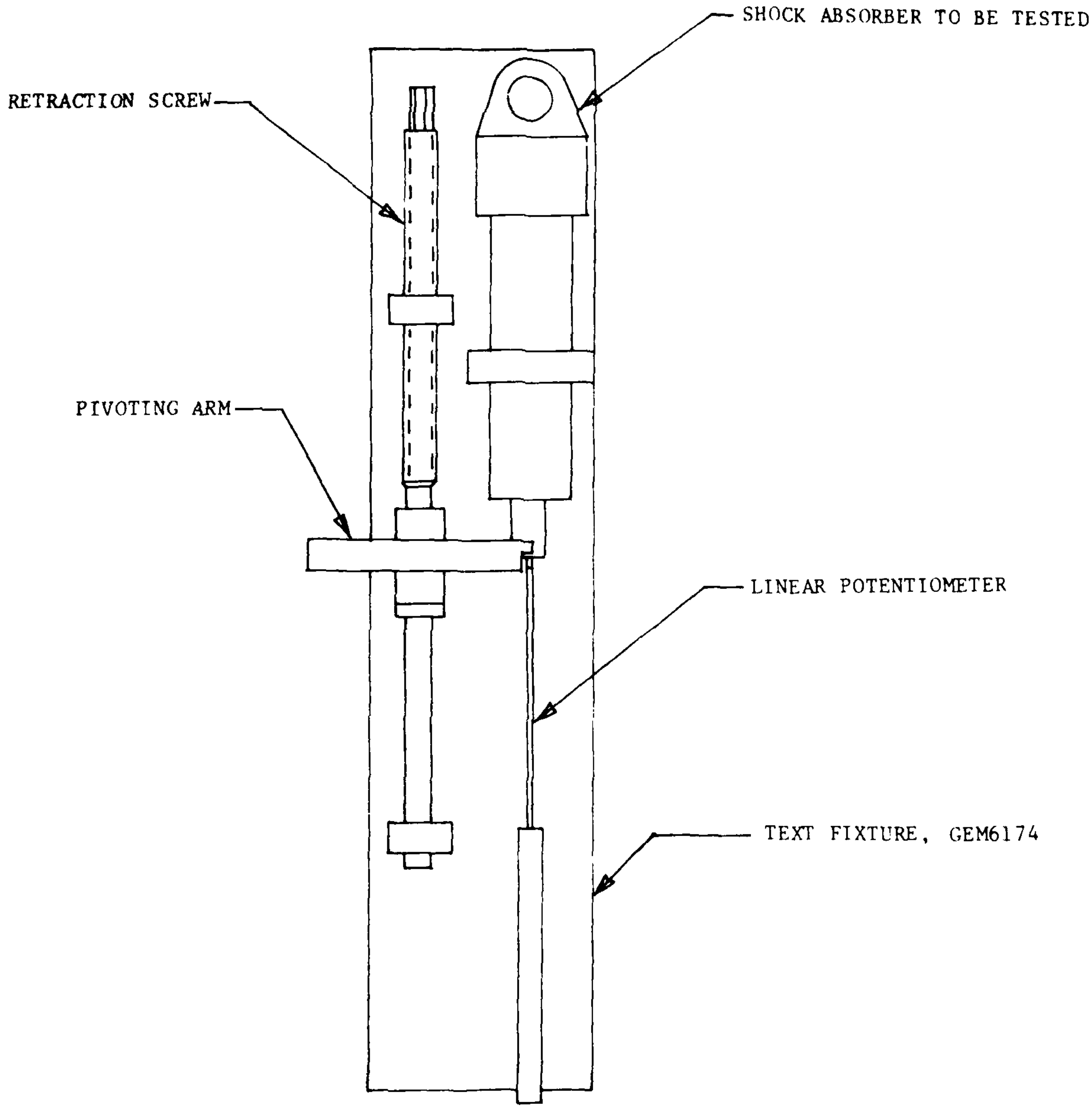


Figure 3. Piston return time test setup.

To start the test the rotating arm is hit with a hammer. The arm rotates away and releases the piston. The compressed air and spring inside the shock absorber drive the piston downward. The piston position is sensed by the linear potentiometer and recorded by an oscillograph. An accelerometer mounted on the rotating arm senses the time that the piston is released.

2. Test Procedure. Piston return tests were initiated on 3 April 1980, but only three could be tested due to an interference between the test fixture and some of the test items due to tolerance variations in the shock absorber body castings.

The test fixture was modified, and on 10 April 1980 the testing was completed. Eight shock absorbers were tested, and an oscillograph trace of piston position versus time was obtained.

3. Test Results. The oscillograph traces were analyzed, and typical traces are shown in Figures 4 and 5. There is normally a very rapid initial response which typically will be a stroke of about two inches in approximately 0.05 sec. This is followed by a slower extension through the full stroke, usually within 0.35 sec. There is always a step in the return cycle, and often more than one step. The piston return is induced by the combination of the forces exerted by the coil spring and the compressed air inside the shock. absorber.

Test results are summarized in Table 2. The times required for piston travel from the compressed position for a distance of 2.00 in., 3.00 in., and full travel (approximately 3.84 in.) are tabulated. Figure 6 shows graphically the distribution of piston return times for the various samples tested.

C. Drop Test

1. Test Equipment. In accordance with the requirements of Note 7 of Drawing 11567877, the units were tested by dropping the shock absorber and a weight of 1000 lb to obtain a velocity of 28 ±1 in./sec at first impact. The test setup is shown in Figure 7. A MRL 3575 Modular Impact 2424 Shock test machine was used. The traveling carriage was ballasted to a weight of 1000 lb and height of drop was varied to yield the desired impact velocity. The load imposed on the shock absorber during the test was sensed by a 5000-lb load cell and recorded on a CEC 5-124 recording oscillograph.

The velocity of the carriage was obtained by integrating the acceleration signal from a strain gage type accelerometer using a HP5451B Fourier analyzer. A special adapter kit, PN GEM 6150, was designed and fabricated to attach the shock absorber to the drop test machine. Position of the carriage during the test was obtained by attaching a 6-inch-stroke linear potentiometer to the carriage with the tip of the potentiometer contacting the base of the machine. The output of the potentiometer was recorded on the oscillograph simultaneously with the load cell output.

2. Test Procedure. The original plan for these tests was to perform a small number of tests on each of the four test samples to demonstrate compliance with the TDP requirements. Compliance was expected, providing the shock absorber modification was done in conformance with the TDP. Early test results quickly negated this strategy when the shock absorber performance in the tests

Table 2. Results of Piston Return Tests

Test Date	Test Code No.	Sample Code	Time For 2-in. Travel (Sec)	Time For 3-in. Travel (Sec)	Time For Full Return (Sec)	Comments
3 Apr 80	P1	3B	.04	.23	.43	
"	P2	"	.04	.23	.41	
"	P3	"	.05	.23	.42	
"	P4	"	.05	.25	.46	
"	P5	5	.14	.28	.41	
"	P6	"	.03	.18	.28	
"	P7	"	.05	.21	.31	
"	P8	4	.16	.31	.43	
"	P9	"	.15	.31	.46	
"	P10	"	.15	.33	.52	
10 Apr 80	P11	8	.30	*	*	See Note 1
"	P12	"	.04	.24	*	
"	P13	"	.05	*	*	
"	P14	5	.03	.18	--	See Note 2
"	P15	"	.03	.14	.26	
"	P16	"	.03	.12	.25	
"	P17	2A	.05	.21	.33	
"	P18	"	.04	.21	.31	
"	P19	"	.04	.21	.32	

Table 2. (Concluded)

Test Date	Test Code No.	Sample Code	Time For 2-in. Travel (Sec)	Time For 3-in. Travel (Sec)	Time For Full Return (Sec)	Comments
10 Apr 80	P20	1A	.03	.15	.32	
"	P21	"	.03	.15	.32	
"	P22	"	.03	.16	.35	
"	P23	6	.04	.28	1.25	
"	P24	"	.04	.26	.57	
"	P25	"	.13	.35	.61	
"	P26	7	.03	.30	.33	
"	P27	"	.03	.10	.85	
"	P28	"	.03	.18	.41	
"	P29	3	.04	.15	.25	
"	P30	"	.03	.14	.23	
"	P31	"	.03	.14	.25	
"	P32	4	.04	.17	.31	
"	P33	"	.04	.17	.32	
"	P34	"	.04	.18	.34	
"	P35	"	.04	.18	.34	

NOTES:
1. * denotes return time too long to be measured; did not completely return in several seconds.

2. -- denotes data lost due to test error.

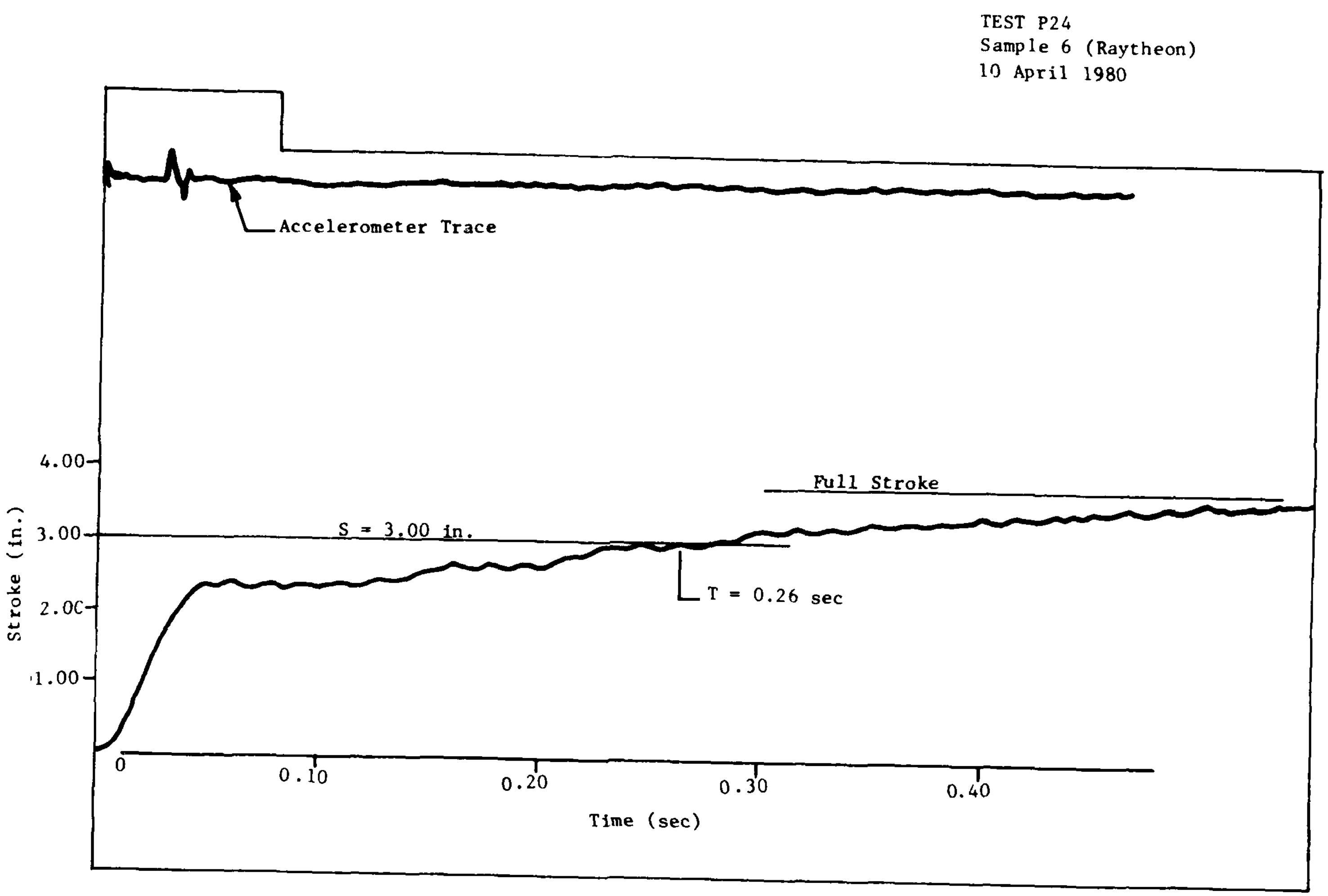


Figure 4. Typical piston return time test oscillograph record.

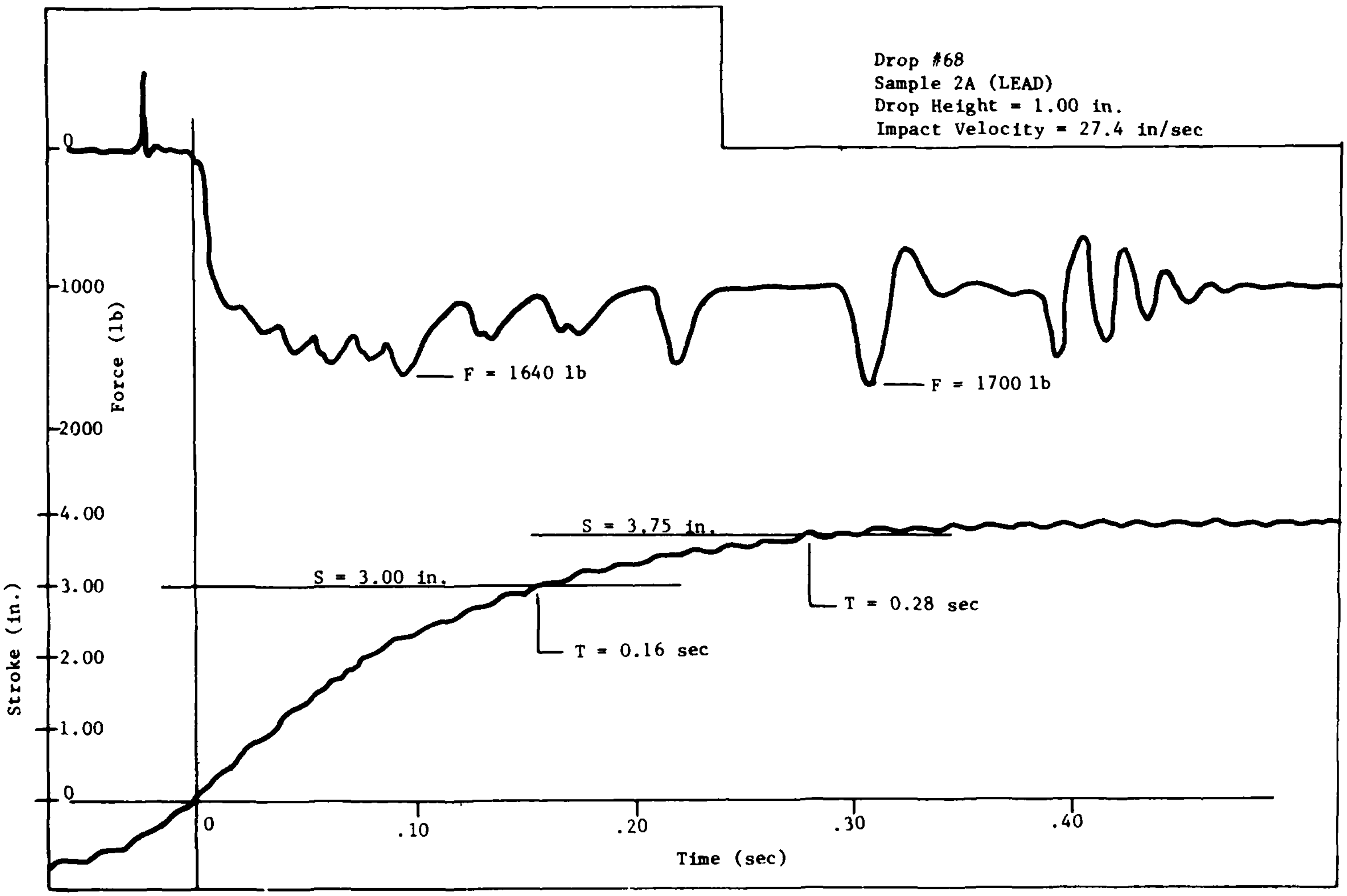


Figure 5. Typical drop test oscillograph record.

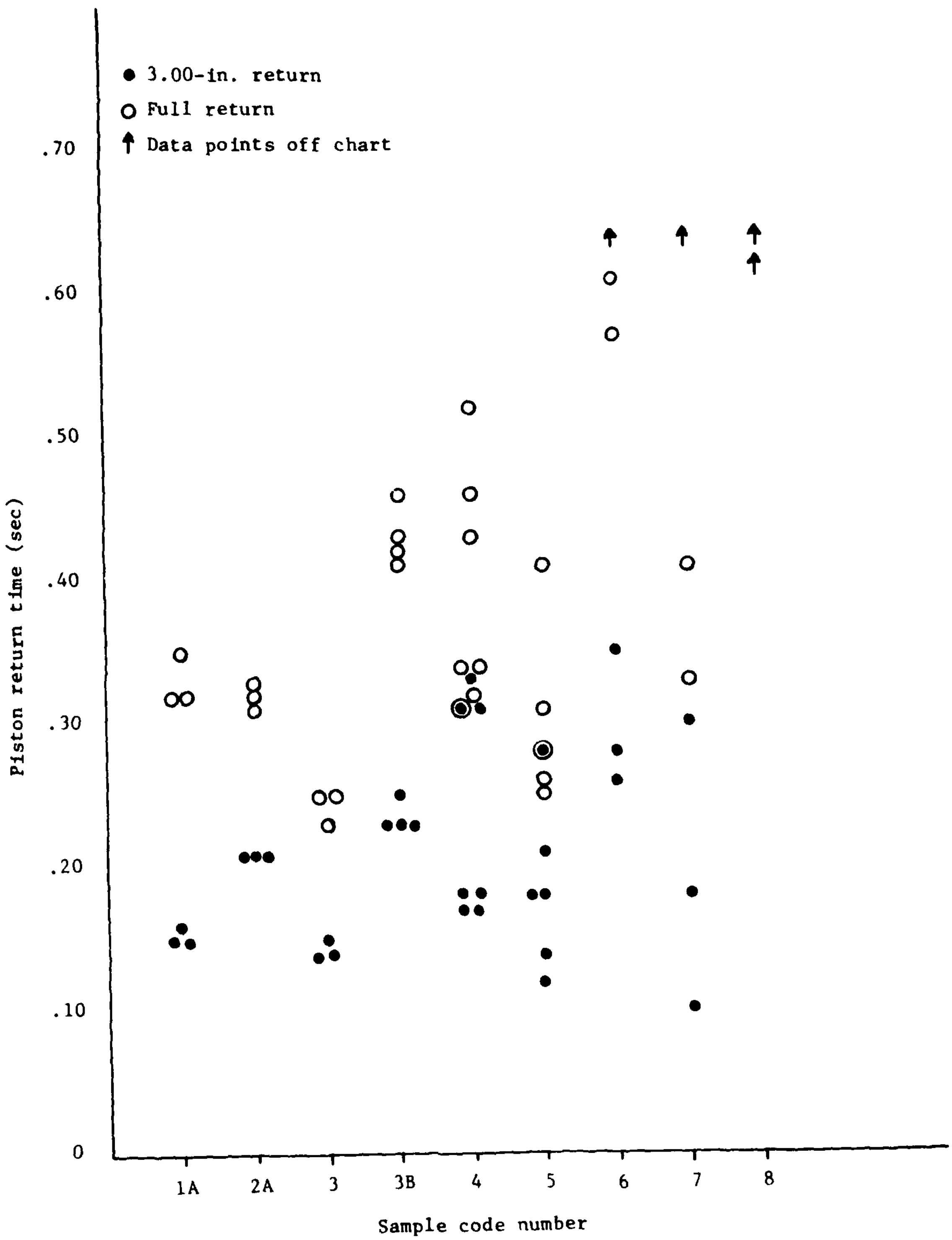


Figure 6. Piston return time distribution.

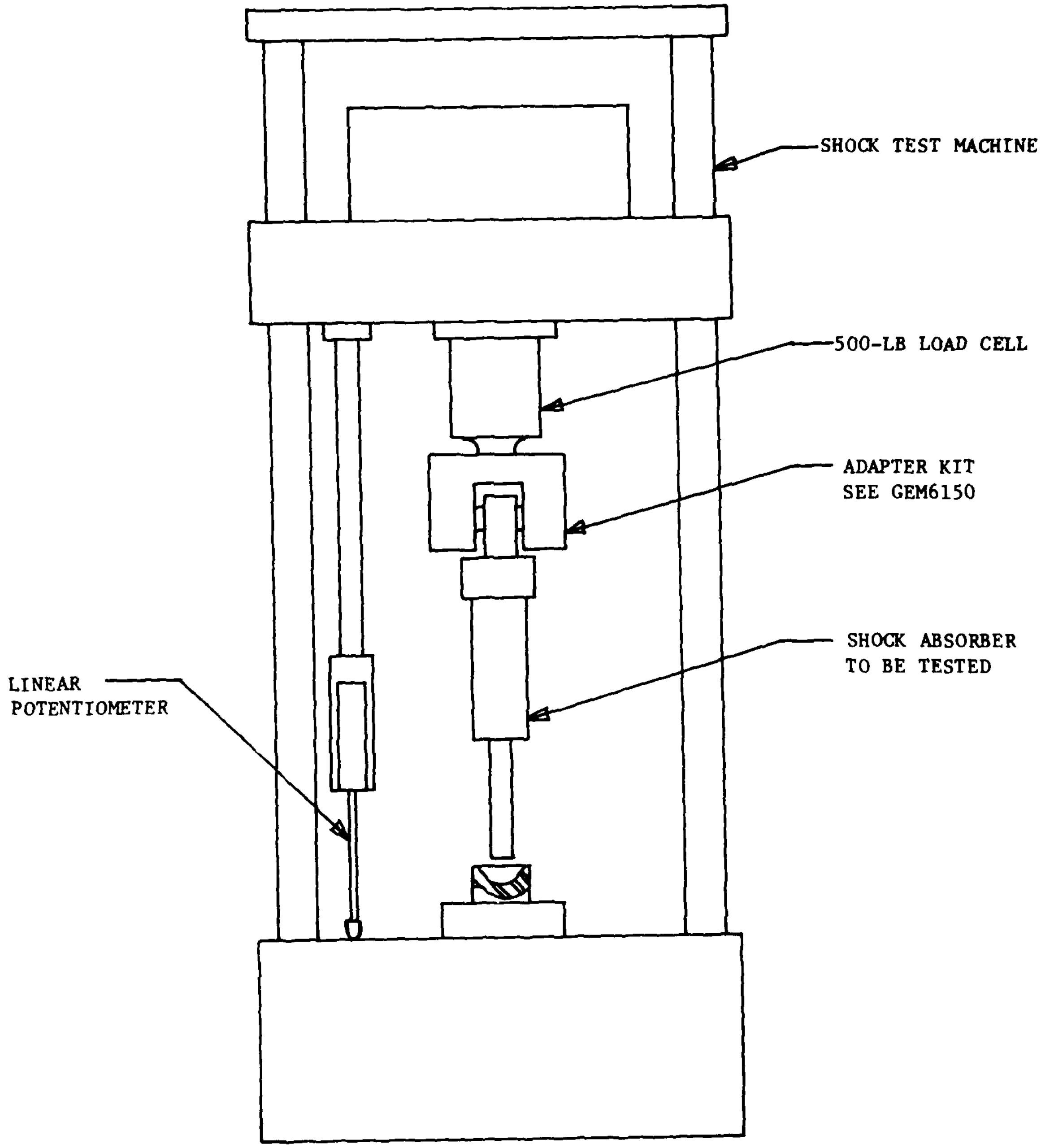


Figure 7. Drop test setup.

fell short of the requirements. The scope of the tests changed as the necessity of generating additional data became apparent.

To a considerable degree, later tests were indicated by the results of earlier tests. A rigid test program was not attempted. In all cases, the test engineer on the scene determined the test sequence, test parameters, and the data to be collected. The data requirements were thus balanced with the availability of test equipment, test samples, and personnel. For this reason the test procedure and test results are highly interrelated, and some test results are included in this section on test procedure.

The TDP specifies a test impact velocity of 28 ±1 in./sec. After assembling the test equipment, the first order of business was to establish the drop height required to yield the correct impact velocity. Early testing utilized an unmodified shock absorber as a test sample to conduct several drops on 11 February 1980. The primary objectives of these tests were the following:

- Check out the test setup.
- Determine the relationship between drop height and impact velocity.
- Establish baseline data on an unmodified shock absorber for comparison with data from future tests of modified shock absorbers.

The impact velocity can be estimated as the velocity of a body falling in a vacuum at one g, less the effects of friction and air resistance. Thus, the velocity of the test item could approach but not exceed the value calculated using the following equations:

$$V = \sqrt{(772.8)S}$$

or

$$S = \frac{V^2}{772.8}$$

where V = Velocity in in./sec

S = Drop height in in.

The theoretical drop height for the impact velocity range of 28 ±1 in./sec is shown in Table 3. The results of these tests are summarized in Table 4. In general, the test data were consistent and apparently accurate, but correlation of drop height and impact velocity was suspect.

On subsequent tests a more accurate method of identifying the precise time of impact was used. The drop height versus impact velocity for the drop tests is shown in Figure 8. As can be seen in Figure 8, the data from the 11 February tests indicate a lower impact velocity for a given drop height than

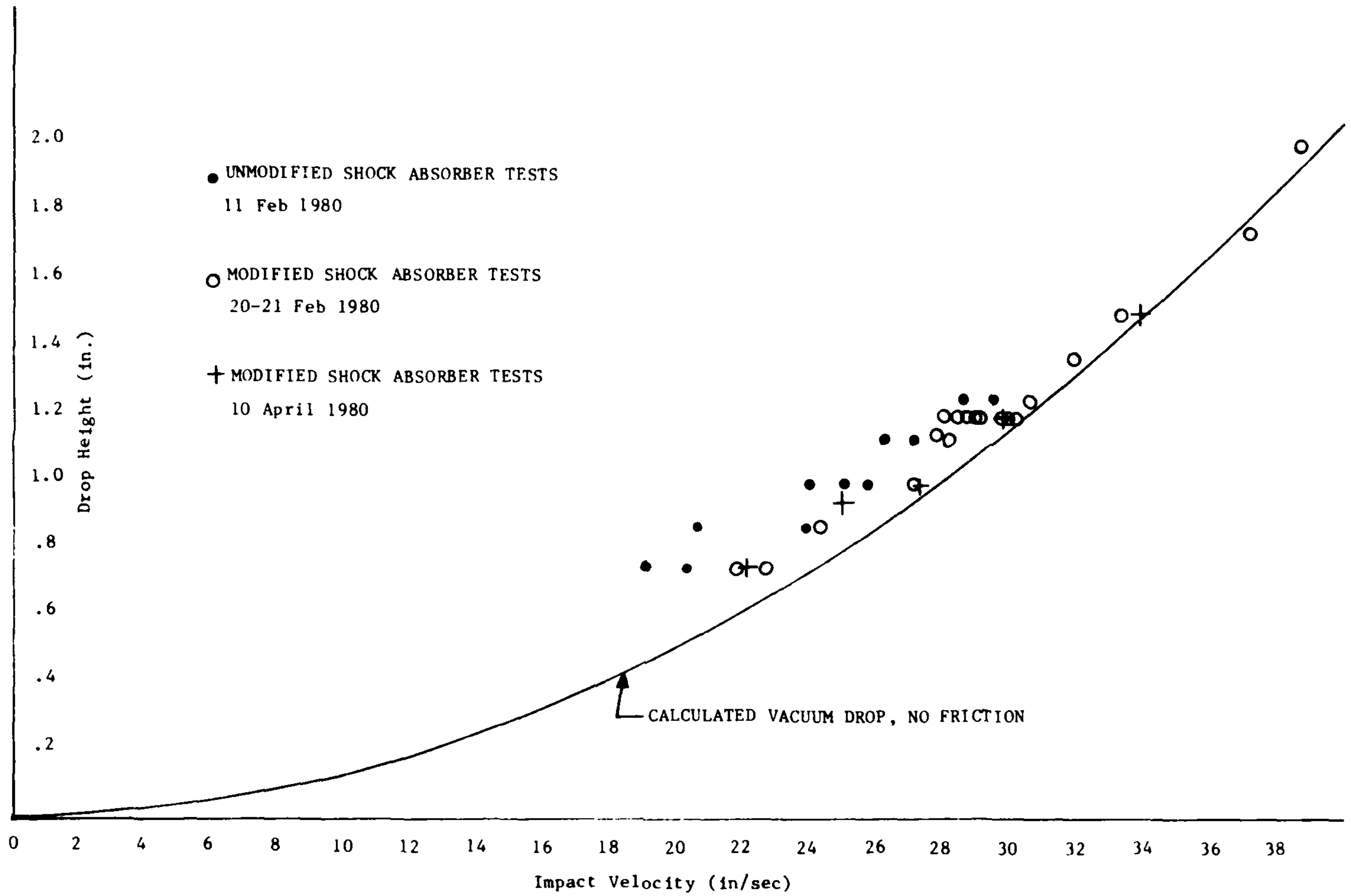


Figure 8. Drop height versus impact velocity.

Table 3. Impact Velocity Versus Drop Height

Impact Velocity (in./sec)	Theoretical Drop Height (Vacuum Drop) (in.)	Measured Drop Height (in.) Min	Avg	Max
27 (TDP min)	0.943	0.98	1.05	1.12
28 (TDP nominal)	1.014	1.06	1.14	1.22
29 (TDP max)	1.088	1.12	1.21	1.30

does the data for later tests. This is because of the previously mentioned revision in the method of evaluating the time of impact. The later data are believed to be correct, and the velocity given for the 11 February tests (Drops 11-1 through 11-10) should be considered less accurate. Table 3 summarizes the height-to-impact-velocity relationship within the range of primary interest.

After the drop-height-to-impact-velocity relationship was established, most future drop tests were conducted without using the computer. This saved time and minimized scheduling conflicts with other tests.

Further tests were conducted at drop heights of 1.00 and 1.20 in. to provide data at both ends of the 28 ±1 in./sec impact velocity. The nominal (28 in./sec) condition can be considered as the average of the 1.0-in. and the 1.2-in. drops. Drops at other heights, including 0.75 in. and 1.50 in., were conducted to provide data both above and below the range of primary interest.

The preliminary tests on 11 February successfully accomplished all objectives and paved the way for tests of modified shock absorbers to begin on 20 February. The results of the 20 February tests caused a revision to the test program, because the shock absorbers did not conform to all the test criteria. More testing would be required to provide data to resolve this problem. The primary objective would be to determine if the LEAD modification was at fault or if the test acceptance/rejection criteria specified by the TDP were too stringent. All tests on 20 February had been conducted using test samples containing the normal amount of hydraulic oil: 250 ml. On 20 February a shock absorber was tested with varing amounts of oil. Except as specified in Table 4, all test samples had 250 ml of oil.

After the 21 February tests, further testing was delayed until additional shock absorber samples could be obtained. The test criteria had been established by the Raytheon Company. Two shock absorbers modified by Raytheon and used to develop the test criteria were obtained for testing to compare them with the shock absorbers modified by LEAD. Two of the four shock absorbers already tested were retained at RSA for further testing, and the other two were returned to LEAD for further modification. These were disassembled, inspected, and reassembled at LEAD using new o-rings and wiper arms. The same body section and sleeves were retained. Each shock absorber sample tested was

Table 4. Results of Drop Tests

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
11 Feb	11-1	0	1.00	25.8	3120	1450	.44		3200	
"	11-2	"	.75	19.1	2400	1410	.45		2480	
"	11-3	"	.88	23.9	2730	1420	.45		2815	
"	11-4	"	1.12	26.2	3350	1500	.44		3440	
"	11-5	"	1.25	28.6	3400+	1500	.44		3740	Note 3
"	11-6	"	1.25	29.5	3400+	1550	.44		3760	
"	11-7	"	1.12	27.1	3400+	1530	.43		4032	
"	11-8	"	1.00	24.0	3400+	1520	.44		3582	
"	11-9	"	.88	20.6	3000	1520	.44		3070	
"	11-10	0	.75	20.3	2900	1500	.44		2960	
20 Feb	1	1	1.20	28.7	1700	1650	*		1719	Note 1

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
20 Feb	2	1	1.20	29.0	1600	1880	*			
"	3	"	1.15	27.8	1640	1930	.28			
"	4	"	1.20	29.1	1650	1950	.27			
"	5	"	1.20	29.0	1650	1950	.27			
"	6	"	1.20	29.0	1700	1950	.27	1985		
"	7	2	1.20	31.8	1650	1730	.27	1750		
"	8	"	1.20	28.5	1600	1750	.28	1782		
"	9	"	1.20	29.0	1650	1830	.27			
"	10	"	1.20	28.4	1650	1840	.27			
"	11	3	1.20	29.2	1650	1700	.28			

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
20 Feb	12	3	1.20	30.0	1650	1650	.28			
"	13	"	1.20	28.0	1670	1650	.30			
"	14	4	1.20	29.0	1650	1900	.29			
"	15	"	1.20	28.9	1600	1880	.28			
"	16	"	1.20	29.2	1600	1820	.29			
21 Feb	1A	4	.75	22.7	1520	1820	.30			
"	2A	"	.88	24.3	1550	1830	.30			
"	3A	"	1.00	27.1	1620	1830	.24			
"	4A	"	1.13	28.2	1650	1830	.30			
"	5A	"	1.25	30.6	1680	1840	.28			

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
21 Feb	6A	4	1.38	31.9	1750	1840	.28			
"	7A	"	1.50	33.3	1720	1850	.28			
"	8A	"	.75	21.8	1550	1850	.30			
"	9A	"	1.75	37.2	1980	1850	.29			
"	10A	"	3.00	46.2	2950	1850	.27			
"	11A	"	2.00	38.7	2200	1870	.27			
"	12A	"	1.20	29.2	1620	1860	.29			
"	13A	"	1.20		1700	1830	.29			225ml oil
"	14A	"	1.50		2000	1830	.29			"
"	15A	"	1.20		2250	1830	.29			200ml oil
"	16A	"	1.50		2600	1900	.27			"

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
21 Feb	17A	4	1.20		3400*	1840	.27			175ml oil
"	18A	"	1.20		1620	1770	.29			275ml oil
"	19A	"	1.50		1680	1780	.29			"
"	20A	"	1.20		*	*	*			"
"	21A	"	1.20		1620	1450	.24			300ml oil
"	22A	"	1.50		1700	1500	.28			"
"	23A	"	1.20		1620	1950	see comments			325ml oil Note 4
2 Apr	24	3	1.00		1660	1700	.30	.17		
"	25	"	1.20		1650	1650	.30	.16		
"	26	"	1.50		1650	1650	.29	.16		

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
2 Apr	27	3	1.00		1650	1670	.30	.17		
"	28	"	1.20		1650	1680	.29	.16		
"	29	"	1.50		1740	1710	.29	.16		
"	30	5	1.00		1660	1650	.30	.16		
"	31	"	1.20		1660	1600	.30	.16		
"	32	"	1.50		1740	1600	.29	.15		
"	33	"	1.00		1650	1600	.30	.16		
"	34	"	1.20		1680	1600	.30	.16		
"	35	"	1.50		1770	1600	.29	.15		
"	36	2A	1.00		1700	1550	.30	.16		
"	37	"	1.20		1720	1630	.29	.15		

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
2 Apr	38	2A	1.50		1950	1600	.28	.15		
"	39	"	1.00		1700	1630	.29	.15		
"	40	"	1.20		1700	1650	.28	.15		
"	41	"	1.50		1950	1630	.28	.15		
"	42	1A	1.00		1650	1830	.26	.16		
"	43	"	1.20		1630	1820	.28	.16		
"	44	"	1.50		1810	1810	.27	.15		
"	45	"	1.00		1650	1840	.28	.15		
"	46	"	1.20		1660	1810	.28	.15		
"	47	"	1.50		1910	1800	.27	.15		
"	48	4	1.00		1640	1800	.30	.16		

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
2 Apr	49	4	1.20		1650	1850	.30	.16		
"	50	"	1.50		1710	1840	.28	.16		
"	51	"	1.00		1620	1800	.30	.16		
"	52	"	1.20		1650	1810	.30	.16		
"	53	"	1.50		1780	1800	.29	.15		
"	54	3B	1.00		1900	1800	.40	.24		
"	55	"	1.20		1950	1760	.40	.24		
"	56	"	1.50		2440	1720	.39	.23		
"	57	"	1.00		1760	1730	.39	.24		
"	58	"	1.20		2150	1700	.39	.23		
"	59	"	1.50		2600	1710	.39	.23		

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
2 Apr	60	6	1.00		1680	1700	.27	.15		
"	61	"	1.20		1730	1700	.27	.15		
"	62	"	1.50		1980	1700	.27	.14		
"	63	"	1.00		1710	1720	.27	.14		
"	64	"	1.20		1780	1740	.26	.14		
"	65	"	1.50		1980	1740	.26	.14		
10 Apr	66	2A	.75	22.1	1640	1600	.26	.14		
"	67	"	1.00	27.3	1660	1630	.28	.15		
"	68	"	1.00	27.4	1640	1700	.28	.16		
"	69	"	1.20		1700	1600	.29	.15		

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
10 Apr	70	2A	1.20	29.8	1700	1600	.28	.15		
"	71	"	1.50	33.9	1820	1600	.29	.15		
"	72	5	1.00	27.2	1600	1570	.31	.17	1657	
"	73	"	1.20	29.8	1660	1580	.25	.15	1665	
"	74	"	1.50		1760	1610	-	.16		Note 3
"	75	8	.75		2880	1760	.44	.32		
"	76	"	1.00		3600+	1740	.42	.31		Note 2
"	77	"	1.00	27.3	3600+	1750	.43	.31	4703	Note 2
"	78	6	.75		1700	1800	.30	.16		
"	79	"	1.00		1730	1860	.27	.15		
"	80	"	1.20		1720	1800	.28	.15		

Table 4. (Continued)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
10 Apr	81	6	1.50		2000	1720	.29	.15		Note 2
"	82	7	.75		3600+	1500	.43	.29		Note 2
"	83	"	1.00		3600+	1500	.45	.30		
"	84	1A	.75		1600	1830	.29	.17		
"	85	"	1.00		1650	1800	.28	.15		
"	86	"	1.20		1710	1800	.28	.15		
"	87	"	1.50		1800	1800	.26	.15		
"	88	4	.75		1600	1770	.31	.16		
"	89	"	1.00		1620	1720	.30	.15		
"	90	"	1.20		1730	1720	.31	.16		
"	91	"	1.50		2000	1780	.28	.15		

Table 4. (Concluded)

Test Date (1980)	Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Max Force During Stroke (lb)	Max Force At End of Stroke (lb)	Time For 3.75-in. Stroke (sec)	Time For 3.00-in. Stroke (sec)	Max Force From Computer (lb)	Comments
"	92	3	.75		1650	1750	.31	.17		
"	93	"	1.00		1700	1800	.31	.17		
"	94	"	1.20		1750	1770	.31	.16		
"	95	"	1.50		1960	1780	.30	.14		

Notes:

1. * indicates data which was not collected due to testing errors.

2. Blocks left blank indicate data which was intentionally not collected.

3. The oscillograph, as set up, did not read forces in excess of 3400 to 3600 pounds. In several tests (Drops #11-5 and 82 for example) the force exceeded this limit. This is denoted in Table 4 by listing the highest measured load followed by "+". In these tests the computer did record the entire force (see Drop #77).

4. On Drop #23A with the shock absorber overfilled to 325 ml oil, the piston bottomed on the oil and could not complete the full stroke.

assigned a sample identity code, which is shown in Table 1. The two shocks which were returned to LEAD were Samples 1 and 2. After the rework, they were designated codes 1A and 2A.

LEAD also furnished a spare sleeve with a different orifice hole size combination. When this sleeve was tested, it was installed in shock absorber Sample Code 3, and this combination was identified as Sample Code 3B. When the special sleeve was removed and the original sleeve reinstalled, this shock absorber reverted to Sample Code 3.

Testing resumed on 2 April when a number of drop tests were conducted without using the computer. Testing was then suspended pending availability of test equipment until 10 April when the final testing was accomplished.

3. Test Results. The results of all drop tests are summarized in Table 4. Typical oscillograph traces are shown in Figures 9 and 10. A sample computer printout is included in the Appendix. All impact velocity data were collected using the computer. In a few drops, the maximum force measured by the computer is included in Table 4. All other data were derived from the oscillograph traces.

As shown in Table 4, the maximum force recorded by the computer is usually slightly higher than the force recorded by the oscillograph; e.g., on Drop #72:

Maximum force from oscillograph	=	1600 lb
Maximum force from computer	=	1657 lb
Difference	=	57 lb
% Difference	=	3.4%

This difference is attributed to the slower response of the oscillograph. The resolution of the computer is also better.

In general, for tests of this type, an absolute accuracy of ±10% is considered good. With the equipment and personnel used for these tests, it is believed that the accuracy was in the range of ±5%, except where very short peak loads occurred. The forces and times listed in Table 4 are believed to be accurate, except that peak loads are a little lower than actual because of the response time of the oscillograph. The equipment, techniques, and accuracy are considered to be entirely adequate for the purposes of these tests.

Analysis of computer data showed that the impact velocity is not equal to the maximum velocity. This is to be expected. The carriage will continue to accelerate for a short time and distance after impact until the resisting force exceeds the gravity force. For example, in Drop #73 the computer showed an impact velocity of 29.8 in./sec and a maximum velocity of 32.0 in./sec about 0.009 sec later. A one-g drop for 0.009 sec would add about 3.5 in./sec velocity. Thus, the measured increase of 2.2 in./sec while the deceleration force is building up to 1000 lb appears reasonable. The impact velocity is of primary interest and is defined as the velocity of the carriage at the time of first contact of the shock absorber piston with the cup surface. The maximum velocity achieved was recorded for several tests. Table 5 summarizes these data.

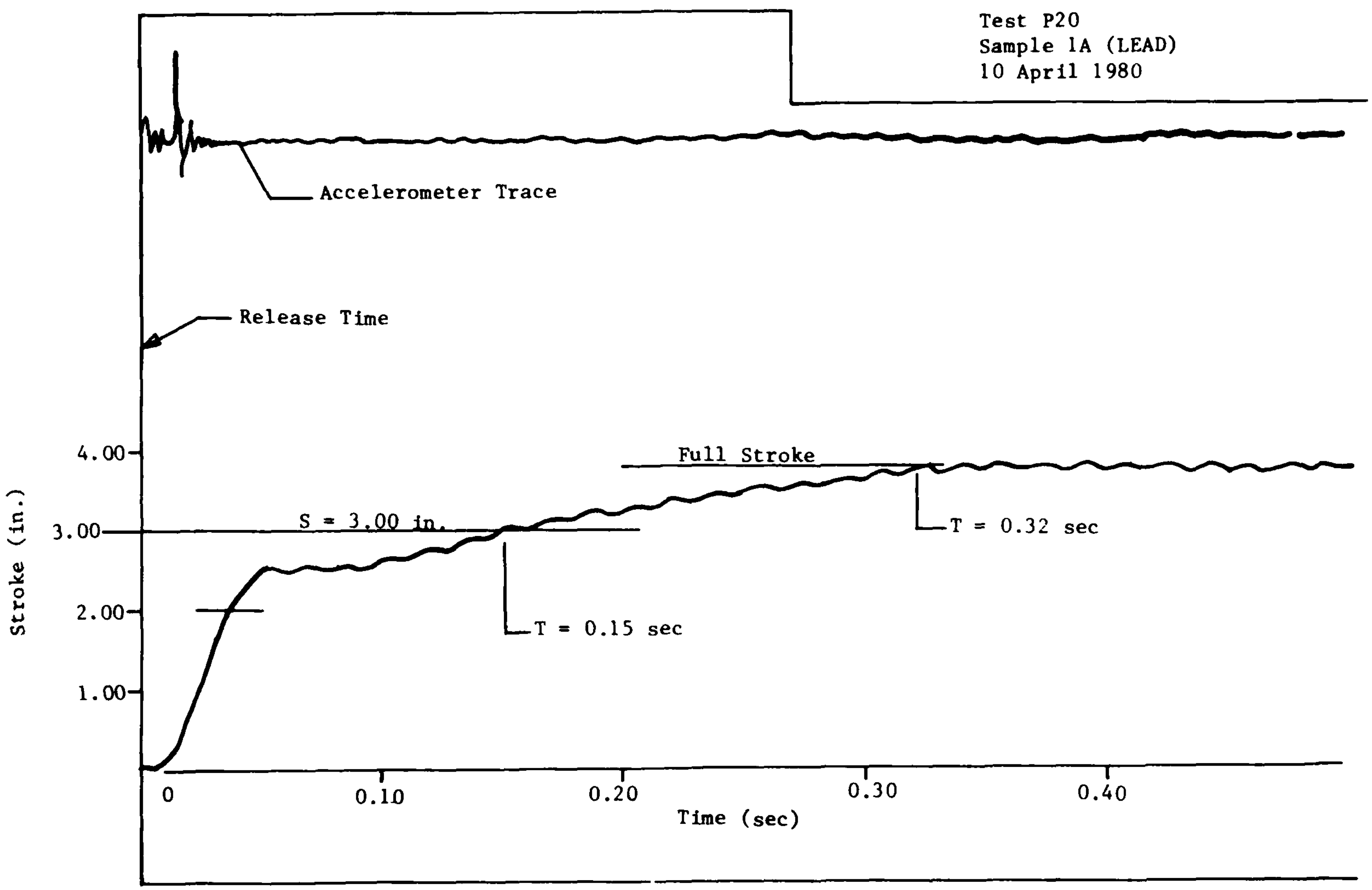


Figure 9. Typical piston return time test oscillograph record.

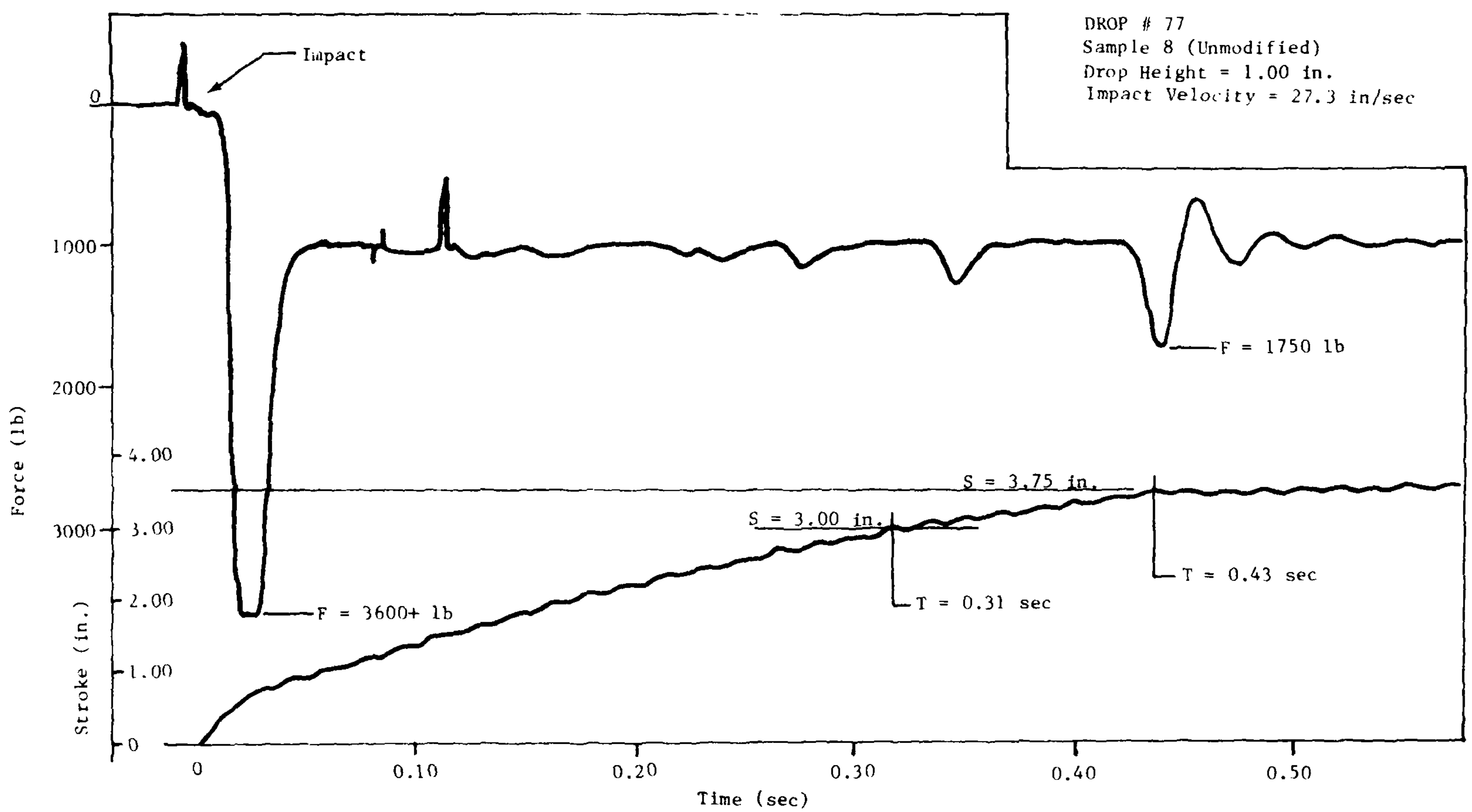


Figure 10. Typical drop test oscillograph record.

Table 5. Comparison of Impact Velocity and Maximum Velocity

Drop Code	Sample Code	Drop Height (in.)	Impact Velocity (in/sec)	Maximum Velocity (in/sec)	Difference (in/sec)	% Difference
66	2A	0.75	22.1	24.9	2.8	12.7
67	"	1.00	27.3	29.6	2.3	8.4
68	"	1.00	27.4	29.2	1.8	6.6
70	"	1.20	29.8	31.9	2.1	7.0
71	"	1.50	33.9	35.8	1.9	5.6
72	5	1.00	27.2	29.2	2.0	7.4
73	"	1.20	29.8	32.0	2.2	7.4
77	8	1.00	27.3	31.5	4.2	15.4

As shown in Figures 9 and 10, during a drop test, immediately after the first impact, the load increases to a peak force. This initial peak represents the energy required to decelerate the 1000-lb weight to a lower velocity, which is then sustained through the remainder of the stroke. Figure 11 shows the magnitude of this first peak is a direct function of impact velocity, i.e., the kinetic energy of the carriage. Figure 11 also shows that the peak load is much lower for the modified shock absorbers than for the unmodified ones.

The subsequent peaks are induced by the 1000-lb weight continuing to force the piston through the rest of the stroke and occur when the orifices are closed by the piston motion. The final peak occurs when the shock absorber reaches the end of its travel and "bottoms" with a metal-to-metal impact. The magnitude of this peak is a function of the carriage velocity at end of stroke and, as shown on Figure 12, is not a function of impact velocity.

This peak at the end of the stroke is often higher than the earlier peaks and frequently exceeded 1650 lb, which is tantamount to failing the test. In an attempt to rectify this problem a special sleeve was prepared with different orifice sizes. This sleeve was tested in Drops 54 through 59 on 2 April. As can be seen from the data in Table 4, this innovation was not successful. The initial peak for Sample 3B is significantly higher than for Sample 3, and the final peak is about the same for both configurations.

Figure 9 shows that during the stroke the force on the shock absorber, as recorded by the load cell, stays near 1000 lb or higher. None of the items tested showed any problem in meeting the requirement that the minimum force during stroke should not be less than 750 lb. Figure 13 shows that if the oil level drops below 250 ml, higher shock absorber forces during stroke are the result. Figure 14 shows that the maximum force at the end of travel is not

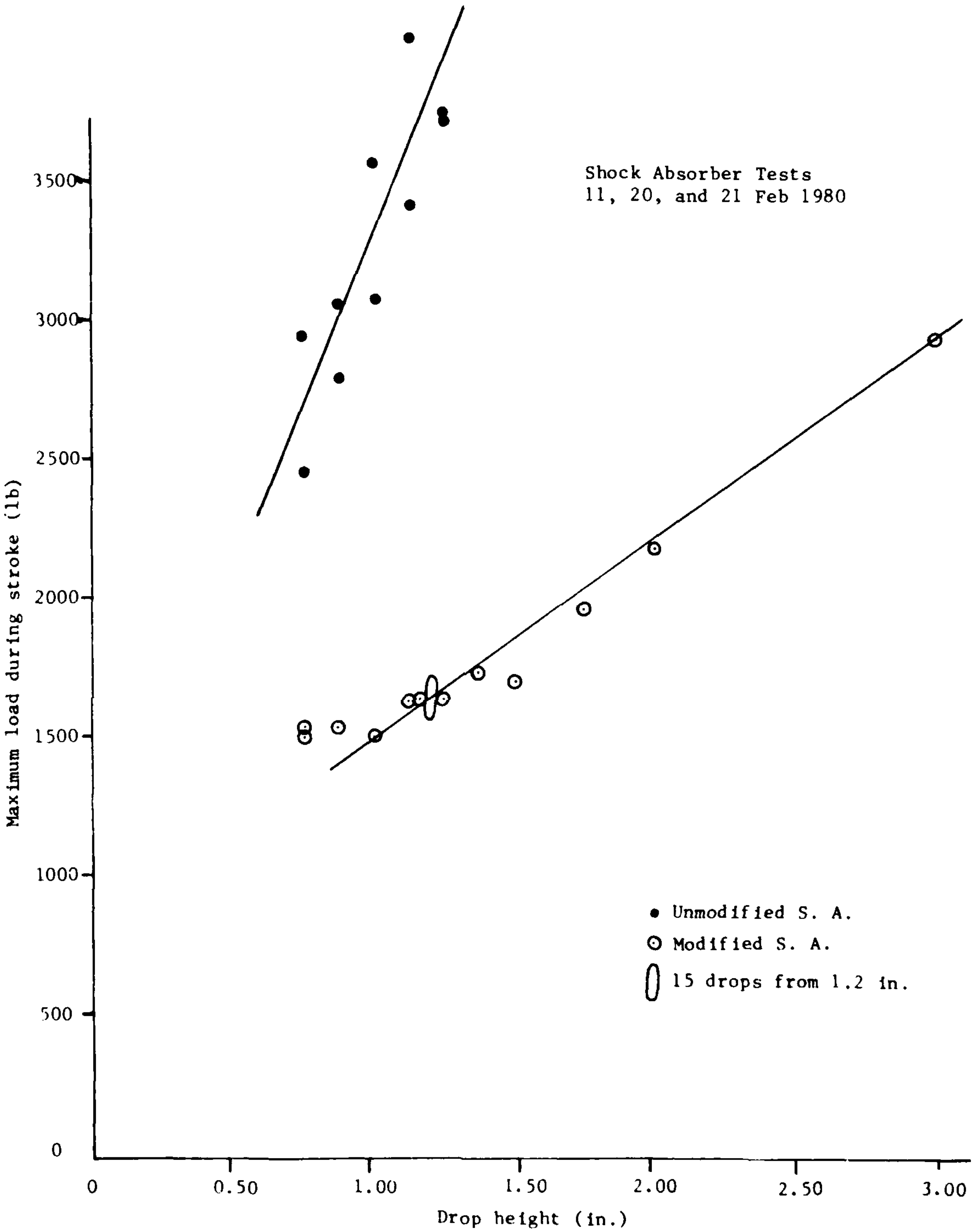


Figure 11. Maximum load during stroke versus drop height.

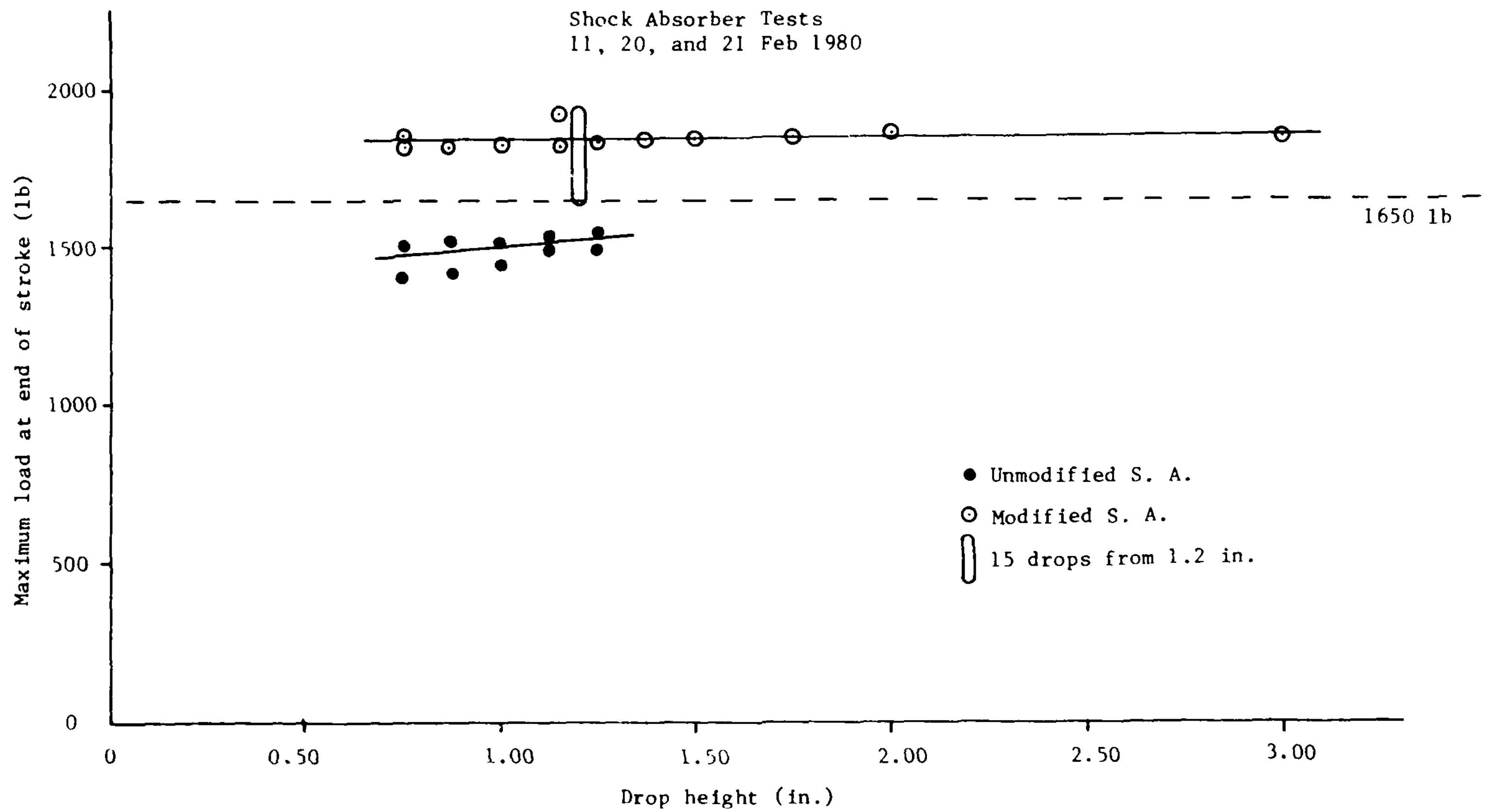


Figure 12. Maximum load at end of stroke versus drop height.

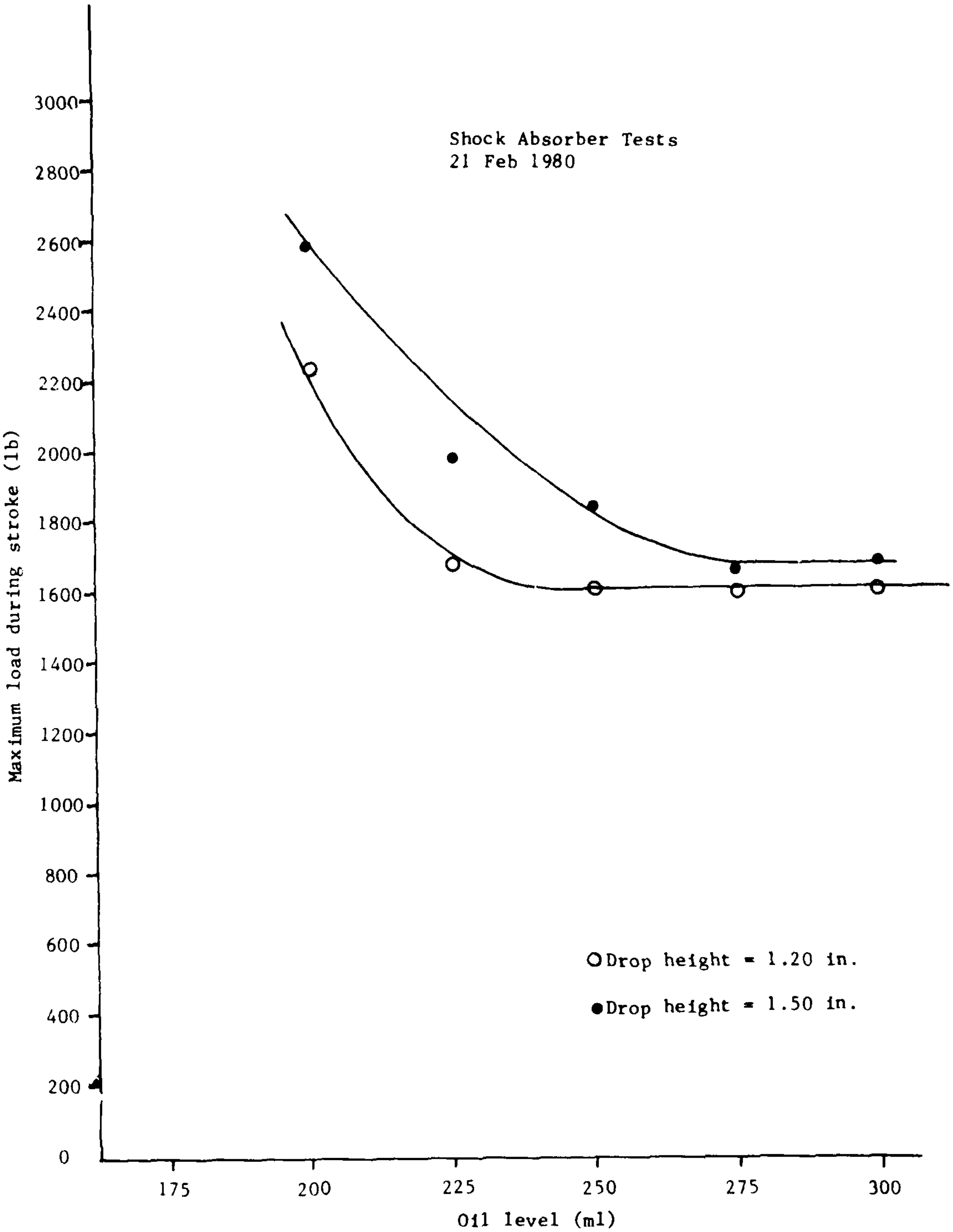


Figure 13. Maximum load during stroke versus oil level.

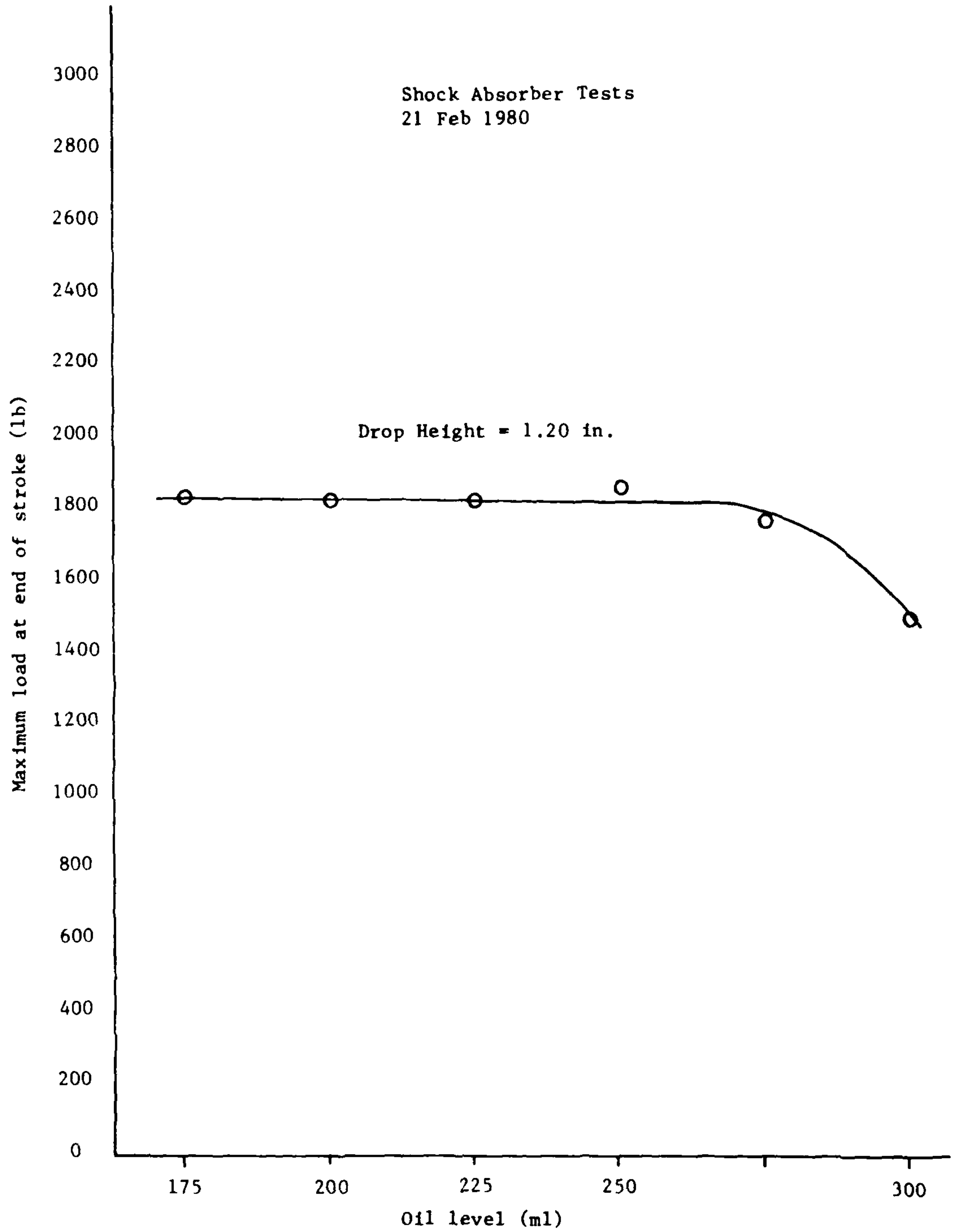


Figure 14. Maximum load at end of stroke versus oil level

affected by changes in shock absorber oil content within the range of 175 to 275 ml of oil.

Figure 15 indicates the following test results:

- In the drop height range of 1.0 to 1.2 in. approximately one-half of the shock absorbers tested failed the test by having shock absorber forces during the stroke in excess of 1650 lb.

- The performance of the LEAD shock absorbers is essentially identical with that of the Raytheon units.

- The performance of the proposed modified sleeve, Sample 3B, is inferior to the standard sleeve modification.

Figure 16 indicates the following test results:

- Maximum force at the end of the stroke is not a function of drop height within the drop height range of 0.75 in. to 1.50 in.

- Six of the nine samples tested (including the special sleeve configuration) failed the test by having maximum forces at end of stroke in excess of 1650 lb.

- There is no significant difference in performance between LEAD shock absorbers and Raytheon shock absorbers.

- The proposed modified sleeve did not improve shock absorber performance.

VI. CONCLUSIONS

A. Check Valve Leakage Test

- The check valves in the shock absorbers modified by LEAD met the test requirement specified by Drawing 11567874, Rev A.

- The leakage allowed by the drawing is extremely high compared with the actual leakage measured during the tests. A leakage rate of 50 ml in 30 sec at 3000 psi is allowed. In fact, there was no significant leakage during the tests.

B. Piston Return Time Test

- Most of the shock absorbers did not meet the required piston return time of 0.25 sec maximum.

- There was no significant difference in the performance of shock absorbers modified by LEAD compared with those modified by Raytheon.

- There was no significant difference in the performance of modified versus unmodified shock absorbers.

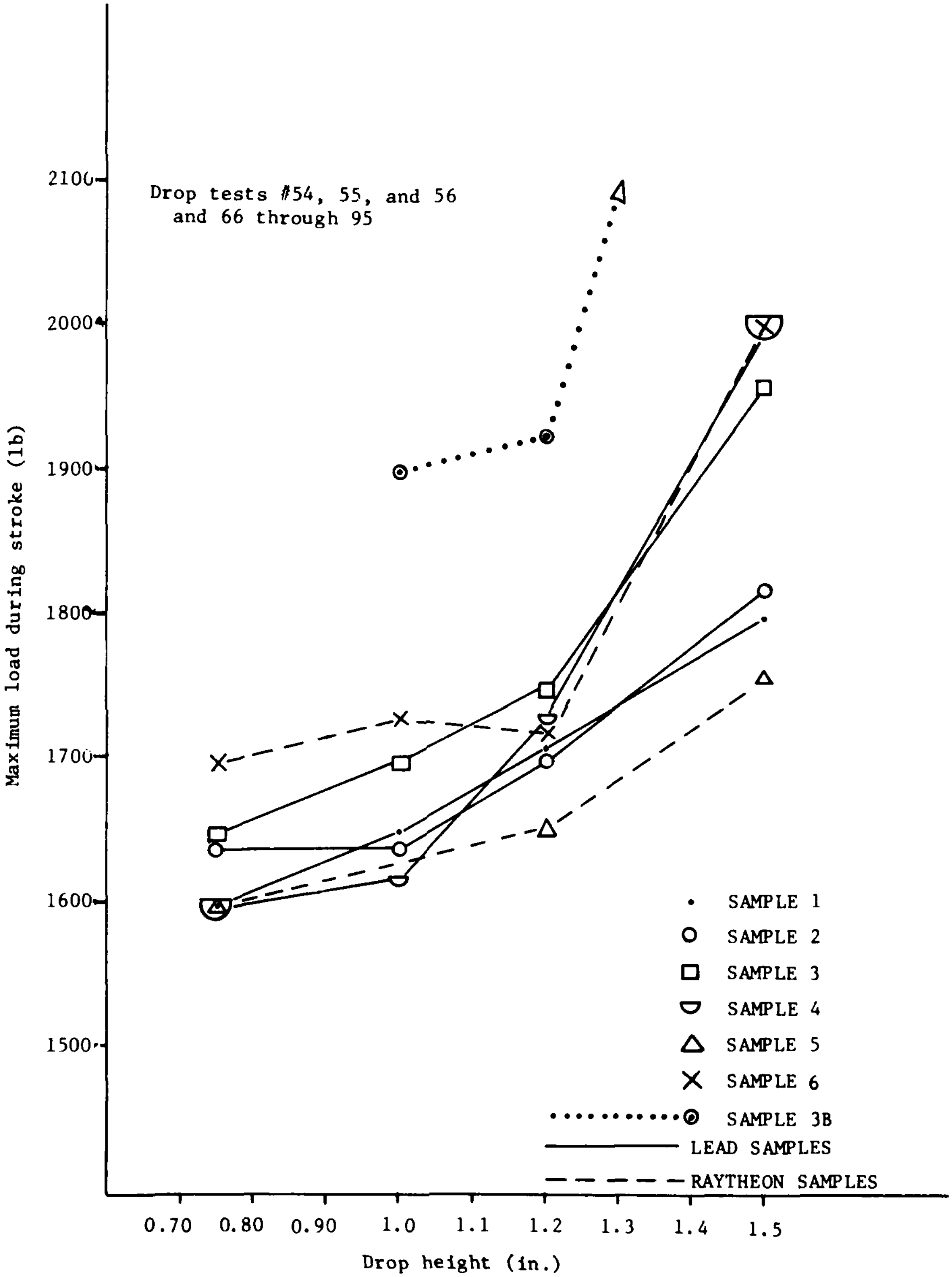


Figure 15. Maximum load during stroke versus drop height.

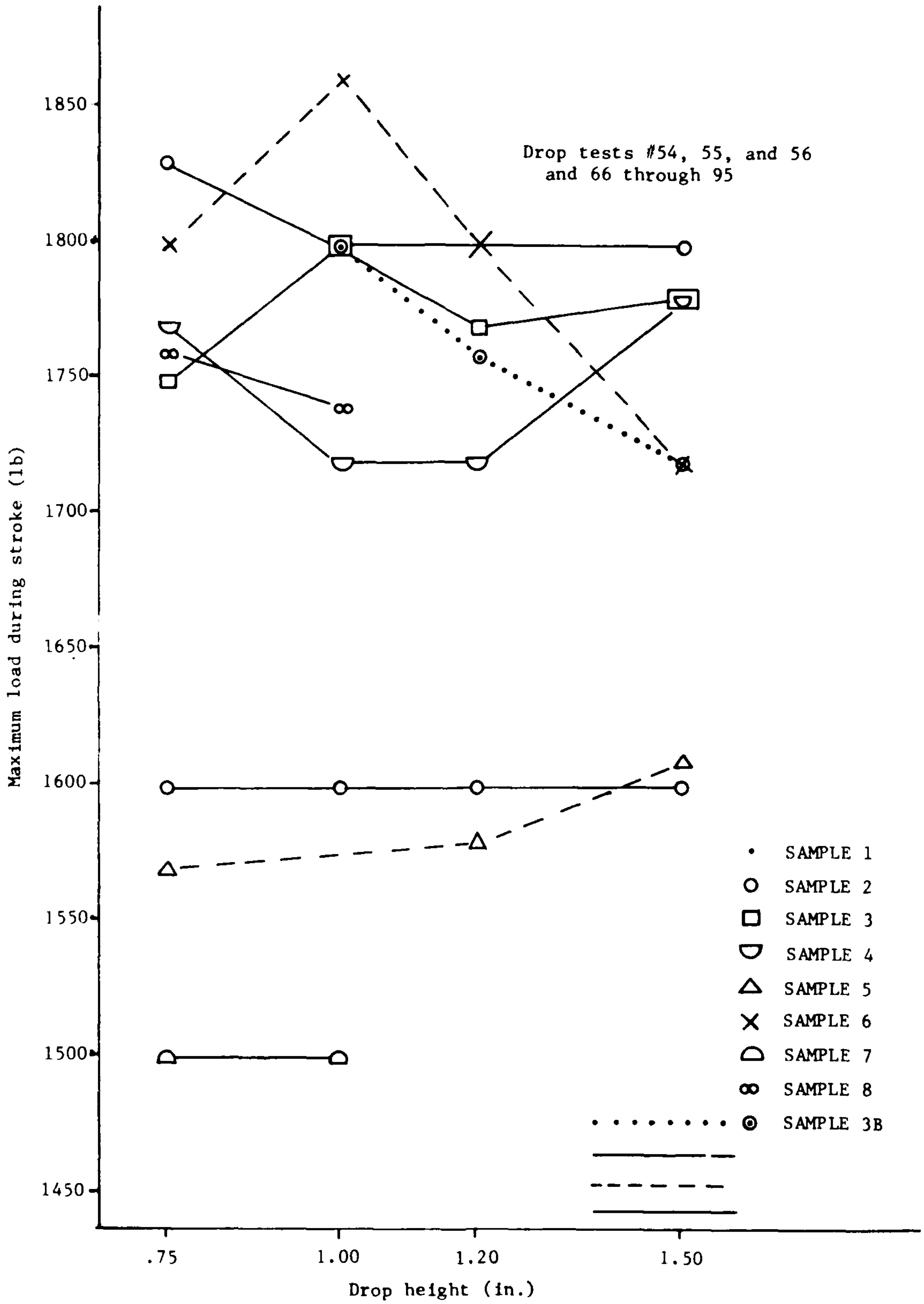


Figure 16. Maximum load at end of stroke versus drop height

C. <u>Drop Test</u>

- Most of the shock absorbers failed to conform to the requirement that the maximum load during the test not exceed 1650 lb.

- All shock absorbers tested met the requirement that the minimum force during stroke not be less than 750 lb.

- Most of the shock absorbers failed to conform to the requirement that a 3.75-in. stroke should take 0.30 sec to 0.42 sec.

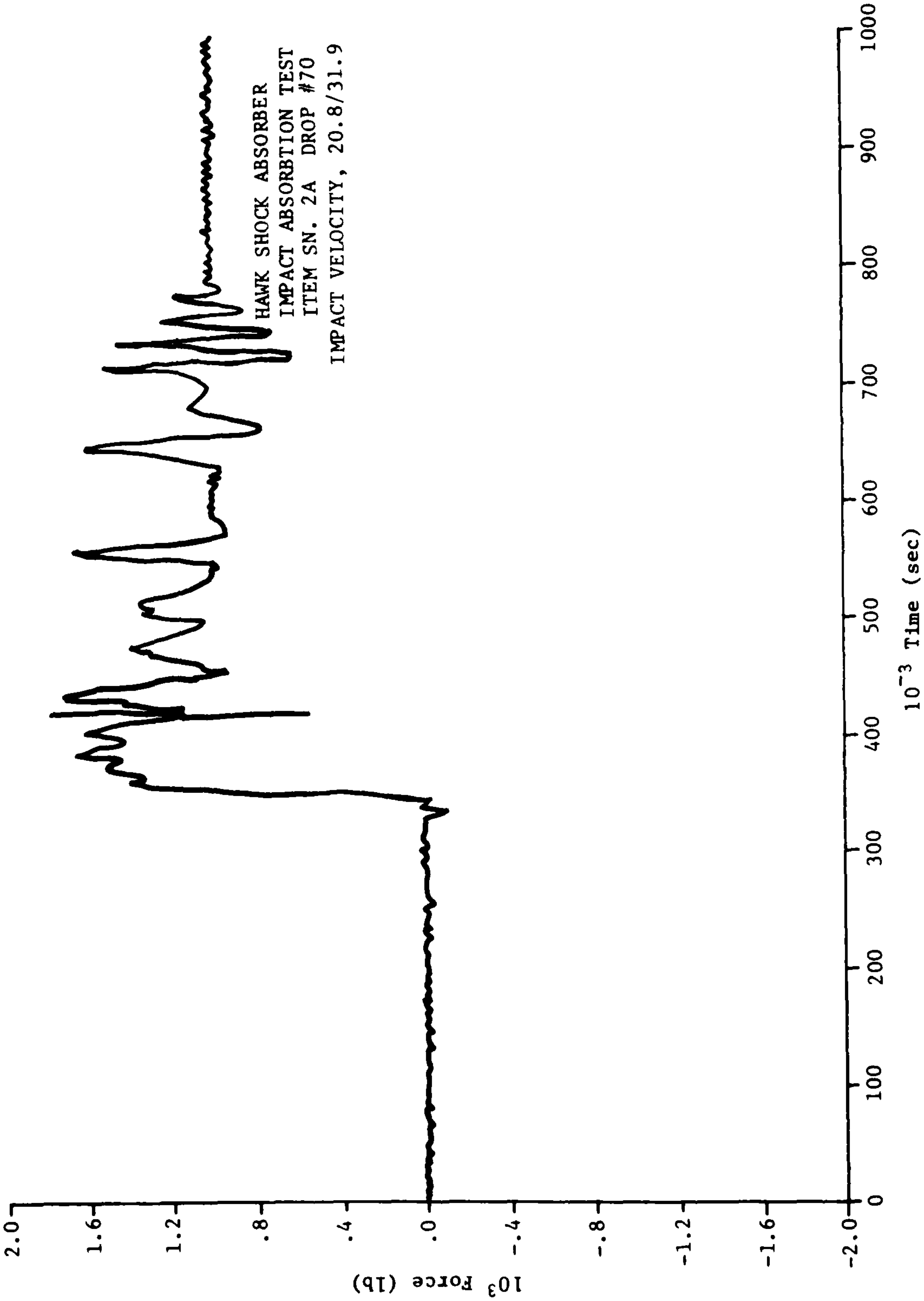
- There was no significant difference in the performance of shock absorbers modified by LEAD compared with those modified by Raytheon.

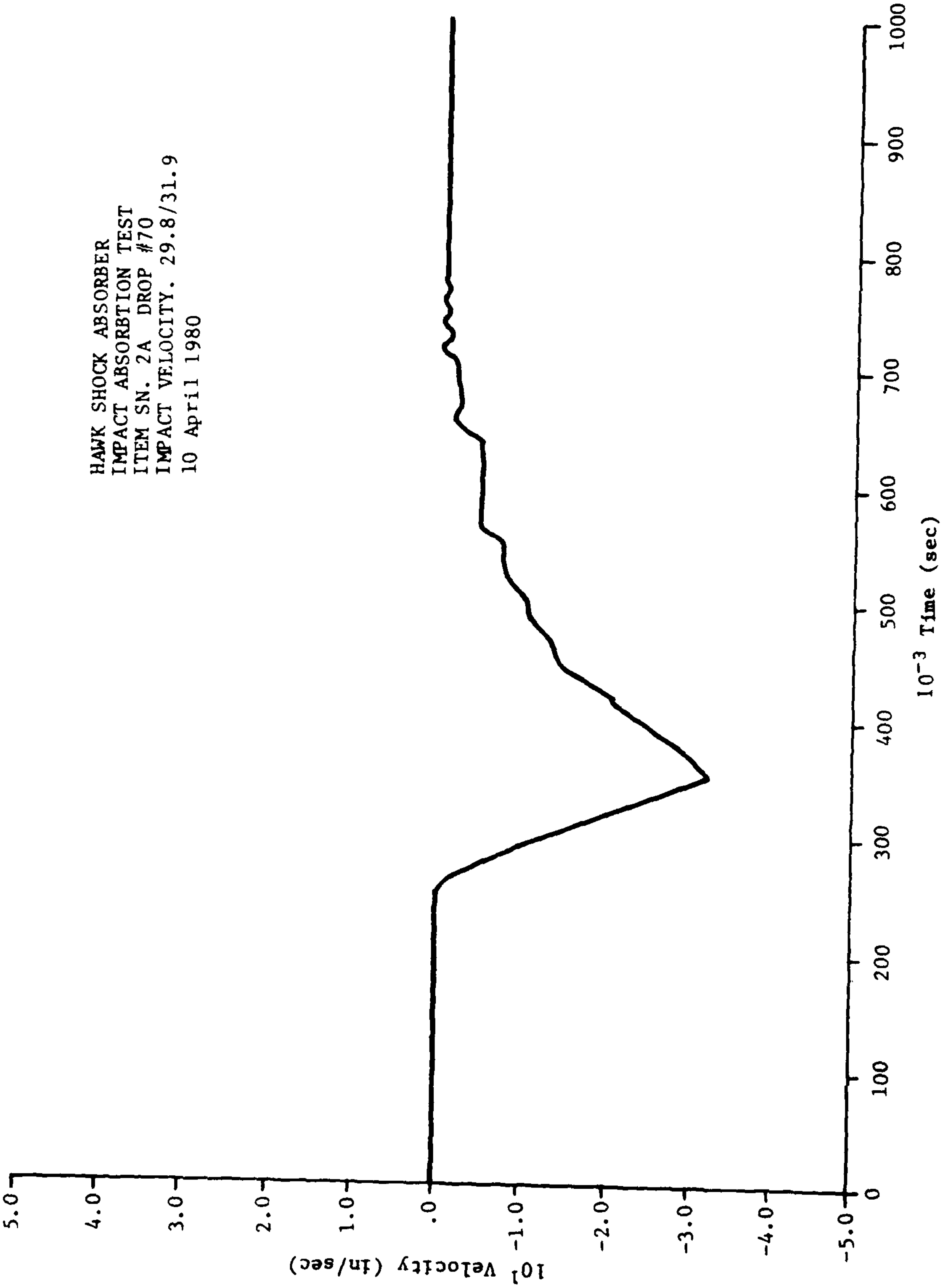
- Performance of modified shock absorbers was far superior to that of unmodified shock absorbers.

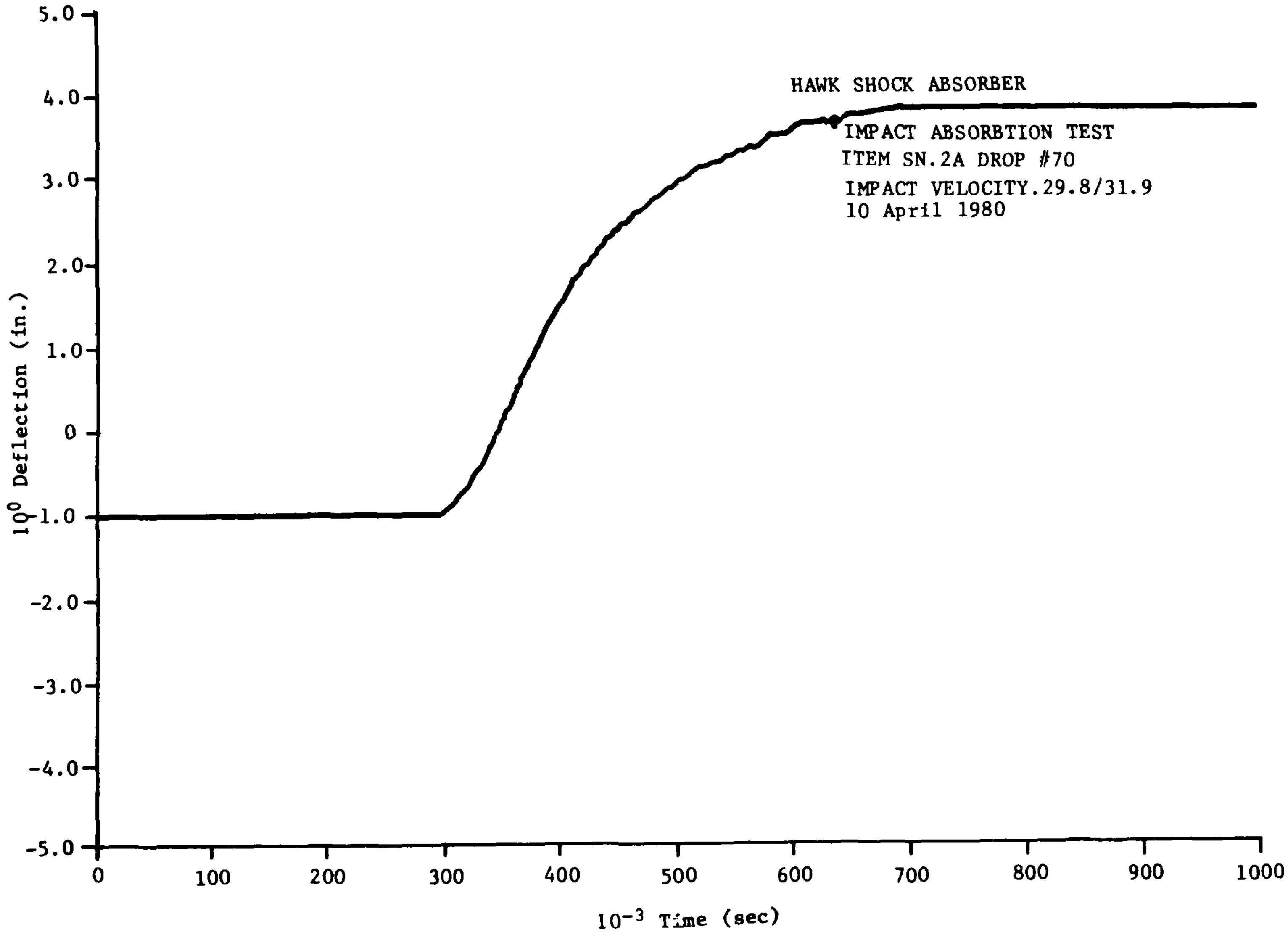
APPENDIX

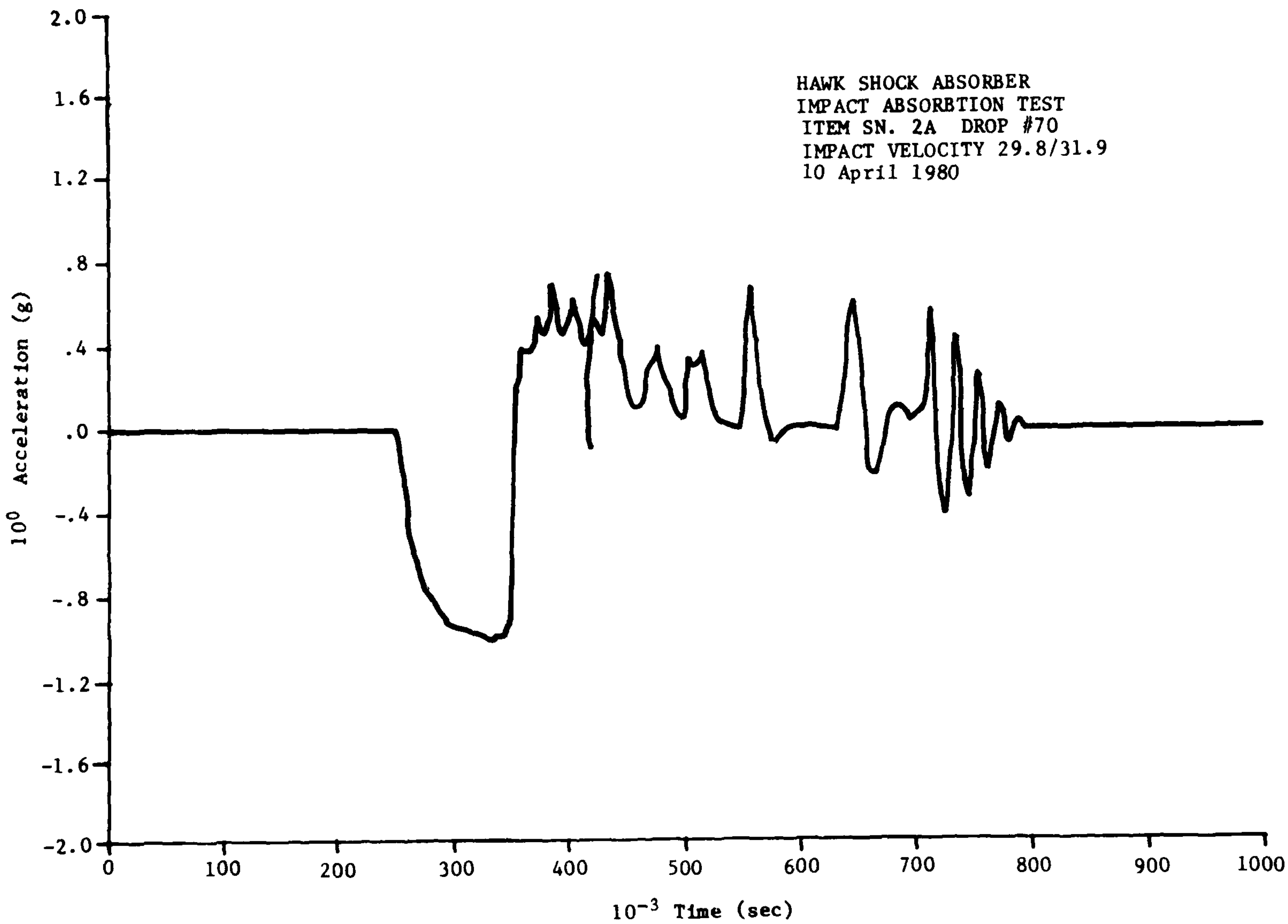
SAMPLE COMPUTER PRINTOUT

IMPACT VELOCITY DATA


HAWK SHOCK ABSORBER
IMPACT ABSORBTION TEST
ITEM SN. 2A DROP #70
IMPACT VELOCITY, 20.8/31.9
10^{-3} Time (sec)
10^3 Force (lb)
0
100
200
300
400
500
600
700
800
900
1000
2.0
1.6
1.2
.8
.4
.0
-.4
-.8
-1.2
-1.6
-2.0


HAWK SHOCK ABSORBER
IMPACT ABSORBTION TEST
ITEM SN. 2A DROP #70
IMPACT VELOCITY. 29.8/31.9
10 April 1980
10^{1} Velocity (in/sec)
5.0
4.0
3.0
2.0
1.0
.0
-1.0
-2.0
-3.0
-4.0
-5.0
10^{-3} Time (sec)
0
100
200
300
400
500
600
700
800
900
1000


HAWK SHOCK ABSORBER
IMPACT ABSORBTION TEST
ITEM SN.2A DROP #70
IMPACT VELOCITY.29.8/31.9
10 April 1980
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
10^0 Deflection (in.)
0
100
200
300
400
500
600
700
800
900
1000
10^{-3} Time (sec)


HAWK SHOCK ABSORBER
IMPACT ABSORBTION TEST
ITEM SN. 2A DROP #70
IMPACT VELOCITY 29.8/31.9
10 April 1980
2.0
1.6
1.2
.8
.4
.0
-.4
-.8
-1.2
-1.6
-2.0
10^0 Acceleration (g)
0
100
200
300
400
500
600
700
800
900
1000
10^{-3} Time (sec)

Velocity (in/sec) $(10)^2$

U 3 300 400

SF	-2	0	57						
(	300)	-1048	-1083	-1117	-1153	-1187	-1223	-1257	-1293
(	308)	-1327	-1363	-1398	-1434	-1470	-1506	-1541	-1577
(	316)	-1613	-1649	-1684	-1721	-1757	-1794	-1830	-1866
(	324)	-1903	-1939	-1976	-2012	-2049	-2085	-2122	-2159
(	332)	-2196	-2233	-2270	-2307	-2344	-2382	-2419	-2457
(	340)	-2495	-2533	-2571	-2608	-2645	-2682	-2719	-2756
(	348)	-2793	-2830	-2867	-2905	-2942	-2979	-3015	-3051
(	356)	-3085	-3118	-3149	-3171	-3183	-3186	-3181	-3173
(	364)	-3165	-3155	-3143	-3129	-3114	-3100	-3085	-3070
(	372)	-3055	-3041	-3027	-3013	-3000	-2984	-2969	-2951
(	380)	-2933	-2913	-2893	-2873	-2852	-2832	-2814	-2795
(	388)	-2778	-2761	-2744	-2725	-2703	-2679	-2654	-2628
(	396)	-2604	-2580	-2557	-2535	-2514			

U 2 360 400

SF	-3	0	57						
(	300)	-1001	-1001	-1001	-985	-954	-954	-954	-938
(	308)	-922	-907	-891	-876	-876	-860	-844	-829
(	316)	-813	-782	-768	-768	-751	-735	-704	-688
(	324)	-672	-657	-641	-610	-594	-579	-563	-547
(	332)	-516	-501	-469	-438	-438	-407	-391	-360
(	340)	-329	-297	-297	-282	-250	-235	-204	-172
(	348)	-141	-94	-94	-63	-32	-1	32	79
(	356)	94	141	157	173	204	250	282	313
(	364)	329	329	391	438	454	500	532	532
(	372)	583	594	625	672	704	719	750	766
(	380)	797	829	860	891	937	938	969	985
(	388)	1016	1032	1063	1110	1126	1141	1172	1204
(	396)	1235	1250	1282	1297	1313			

DROP 970 1.2IN
2A 10 APR 80

Stroke (in.) $(10)^3$

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-RPT (Reference Copy)	1

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